

metal treatment

Vol. 26 : No. 171

DECEMBER, 1959

Price 2/6

Heat treatment

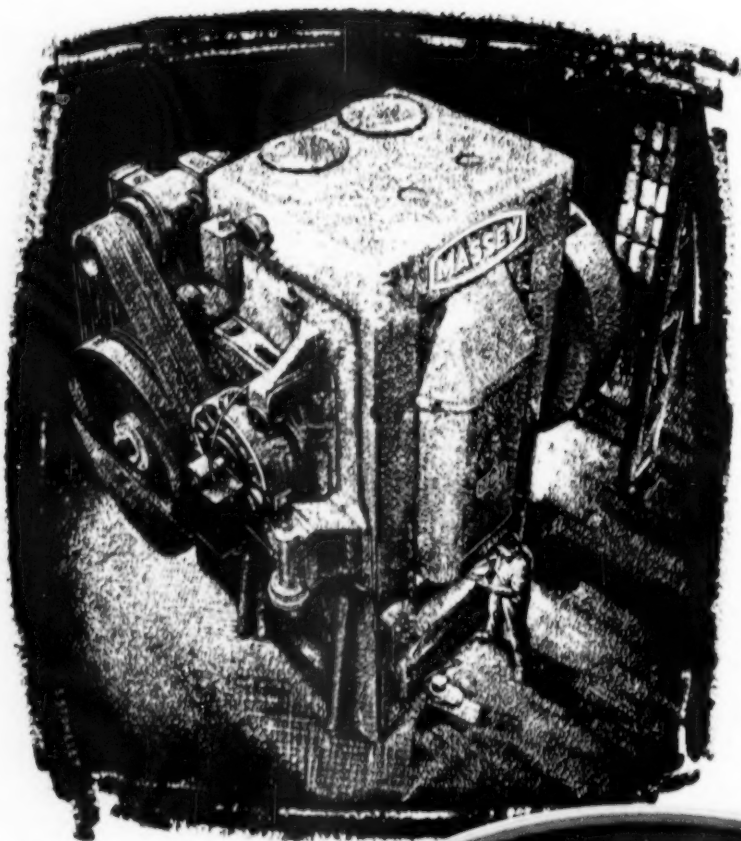
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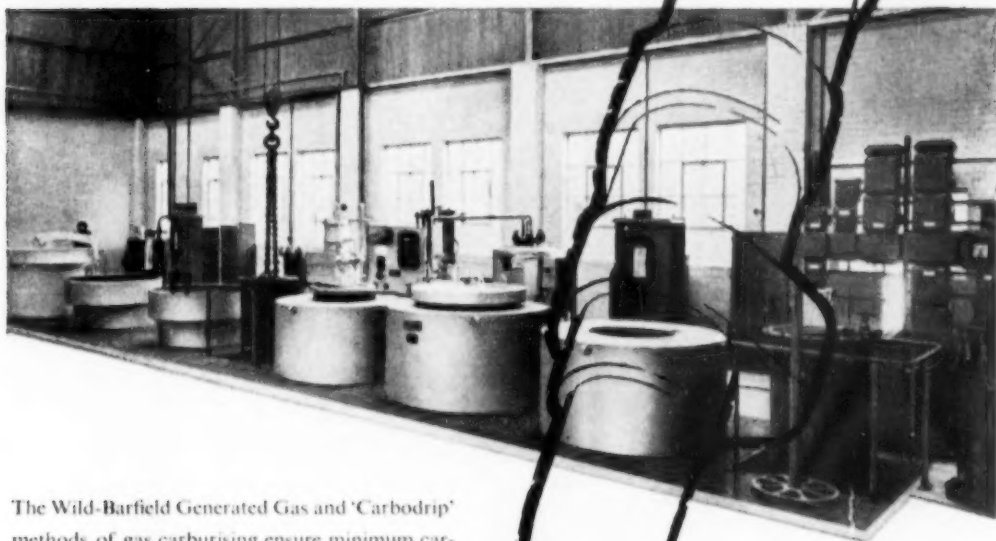
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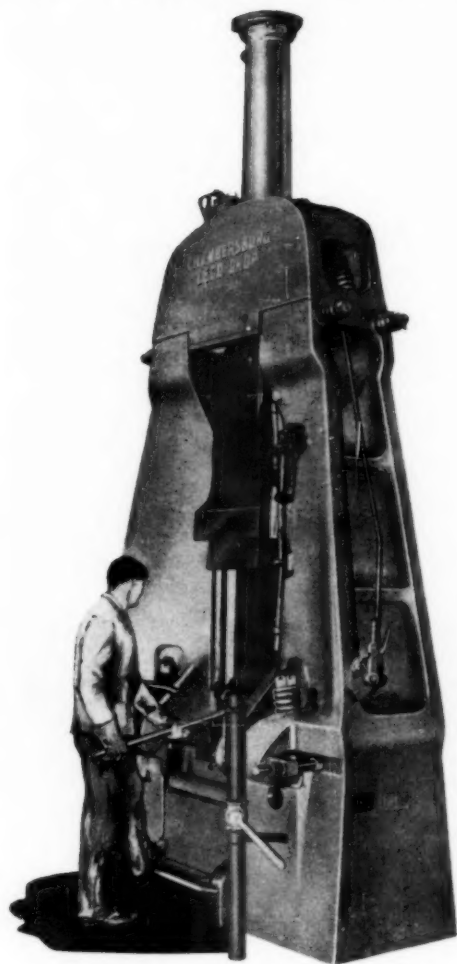
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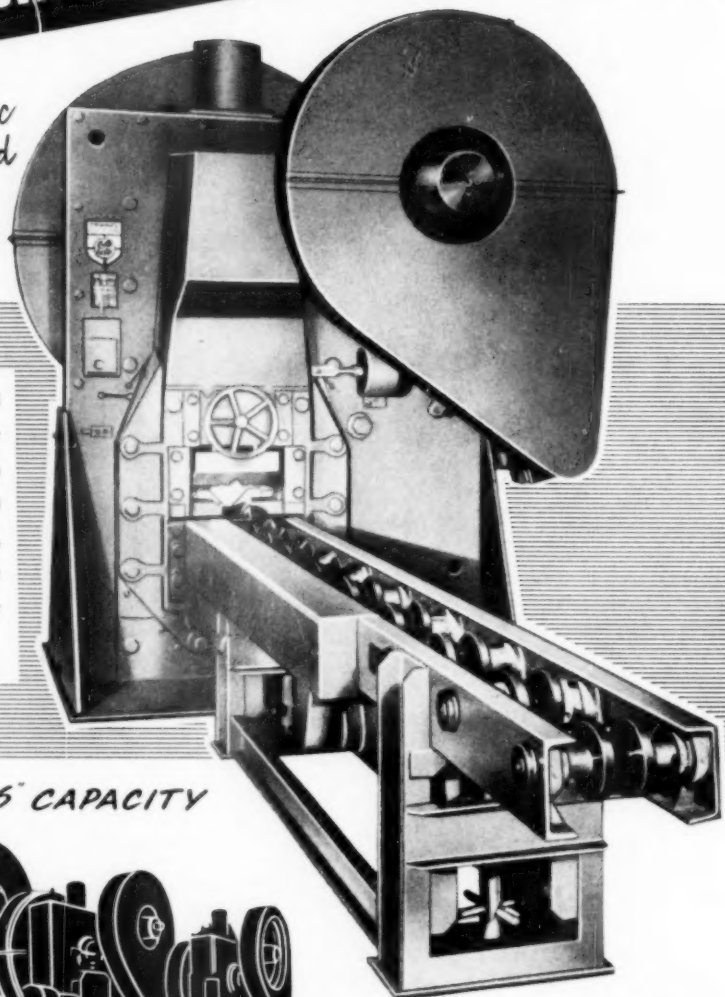
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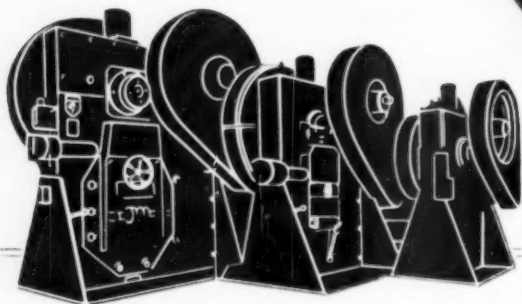
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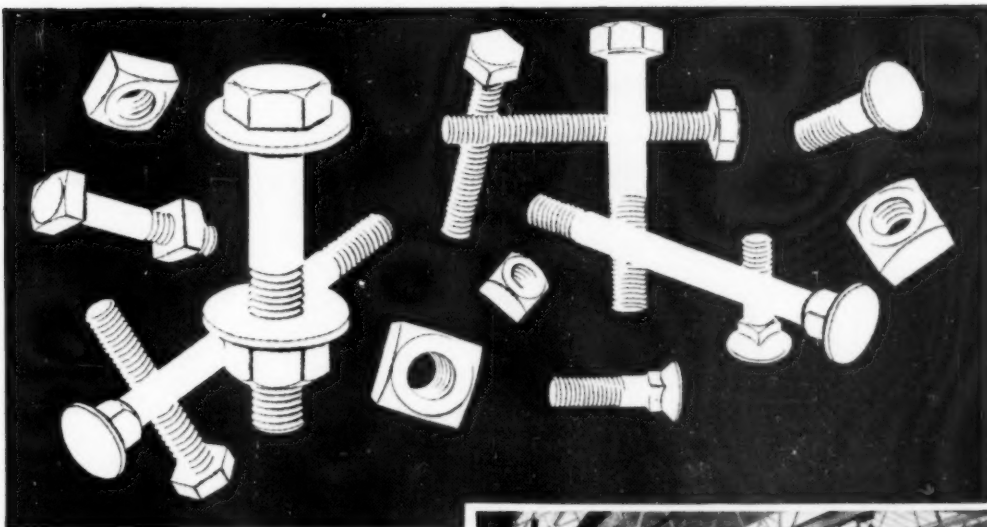
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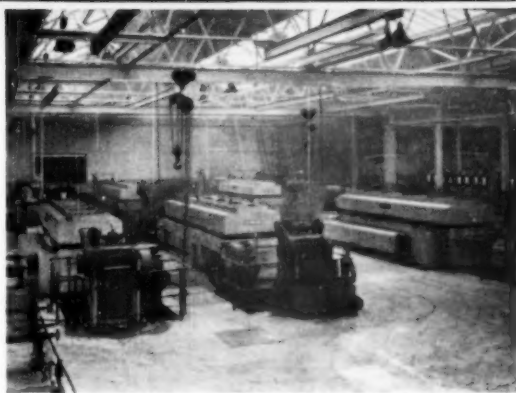
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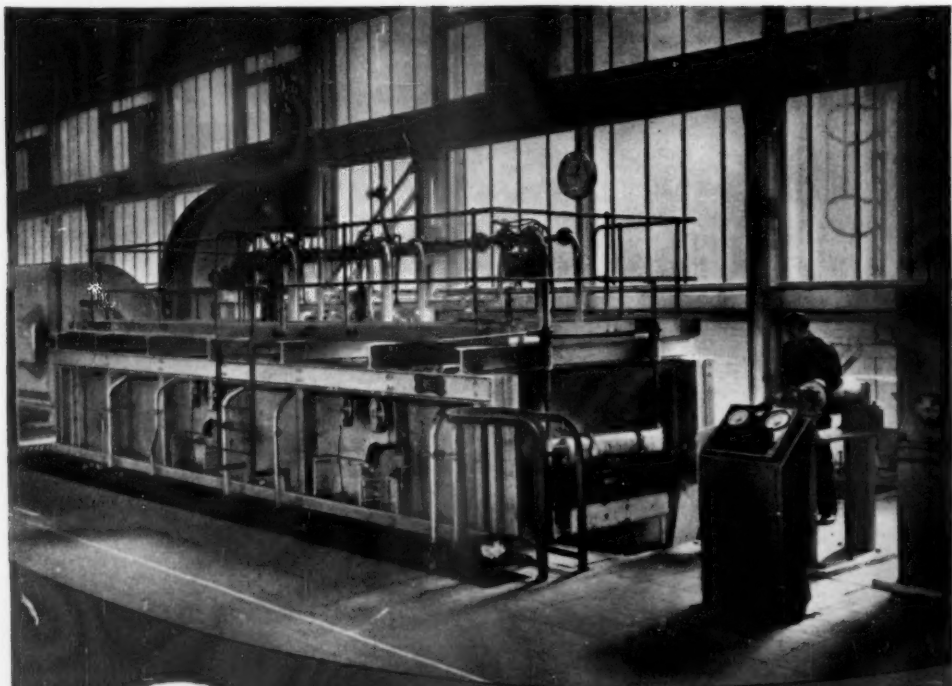
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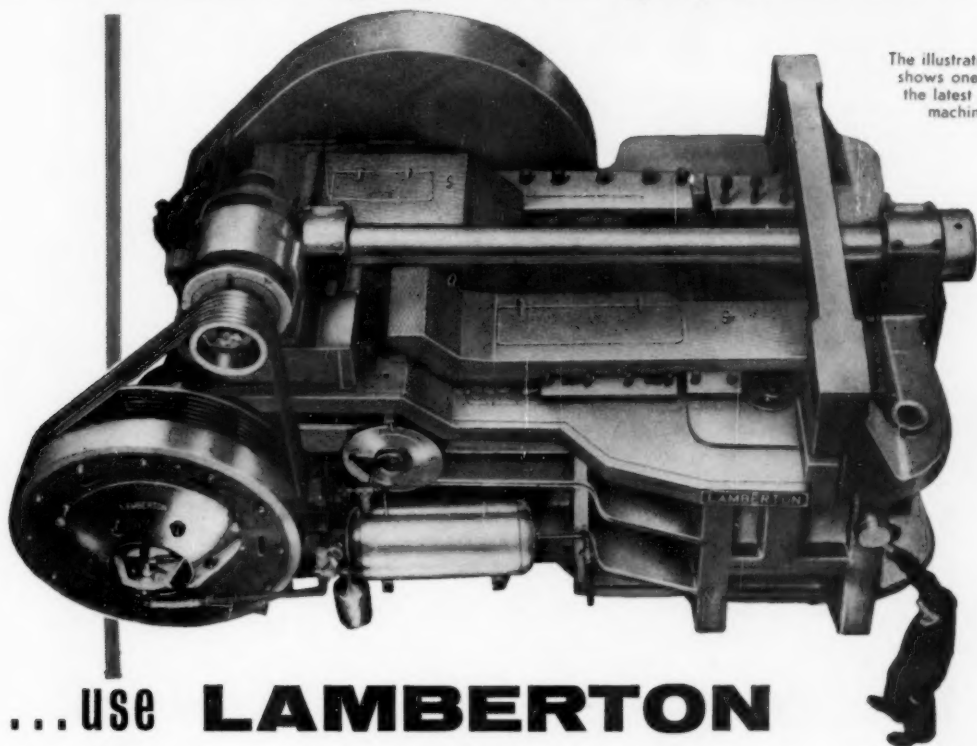
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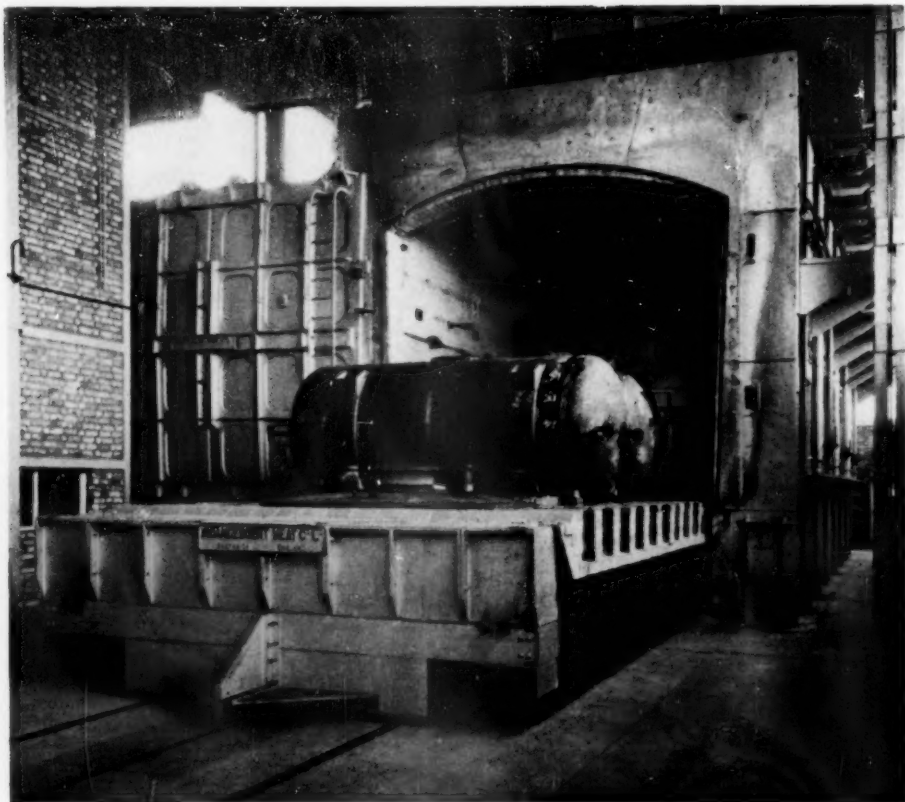
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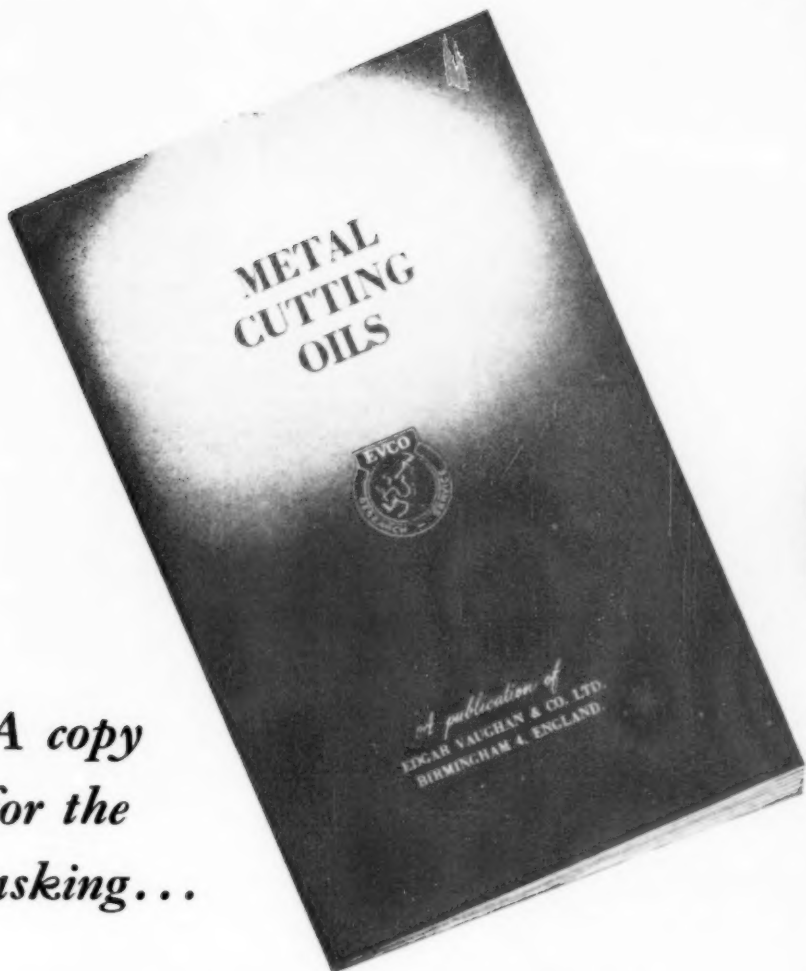
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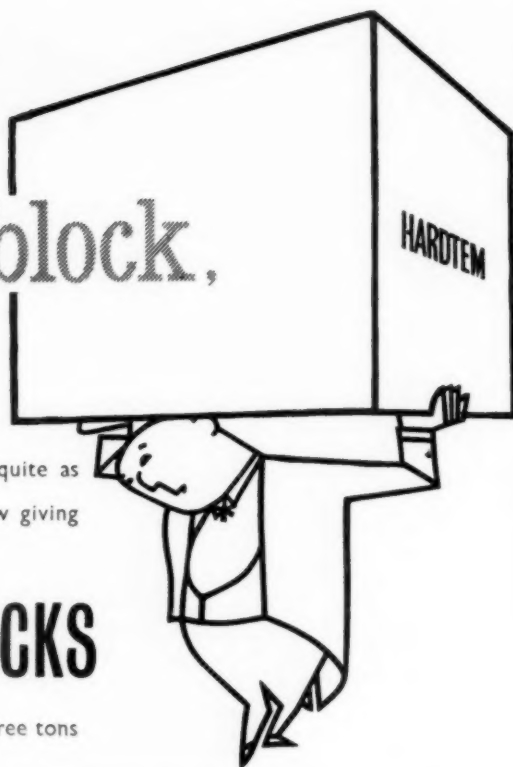
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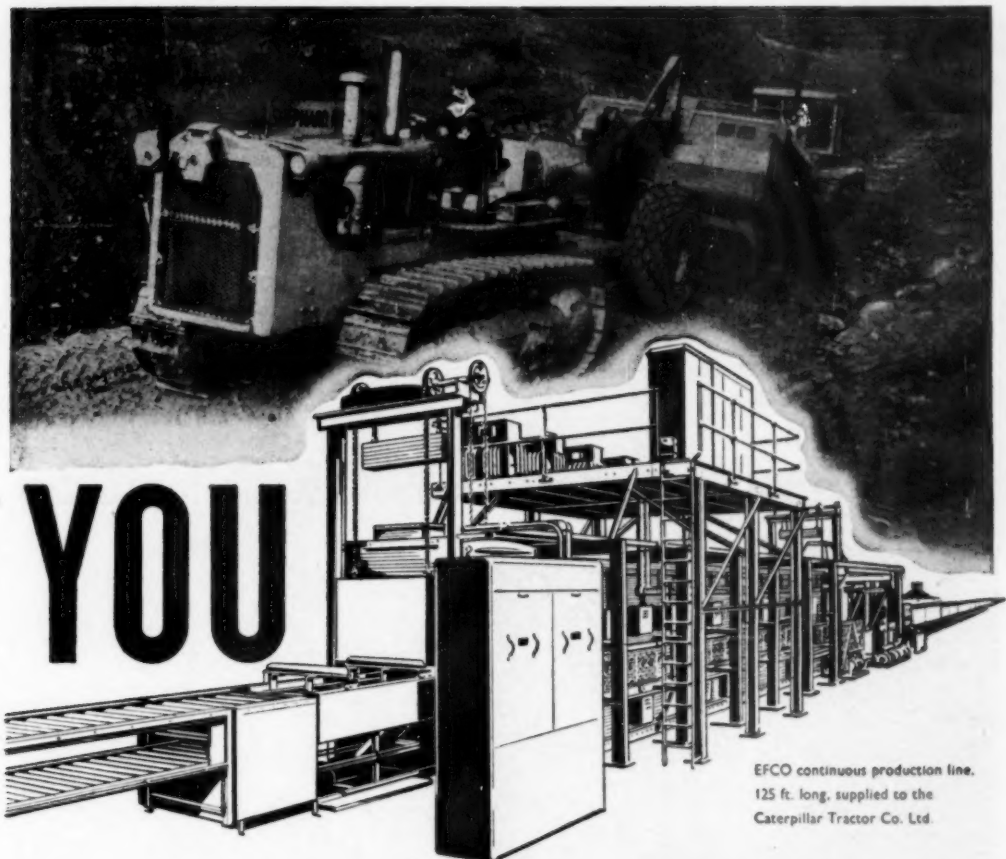
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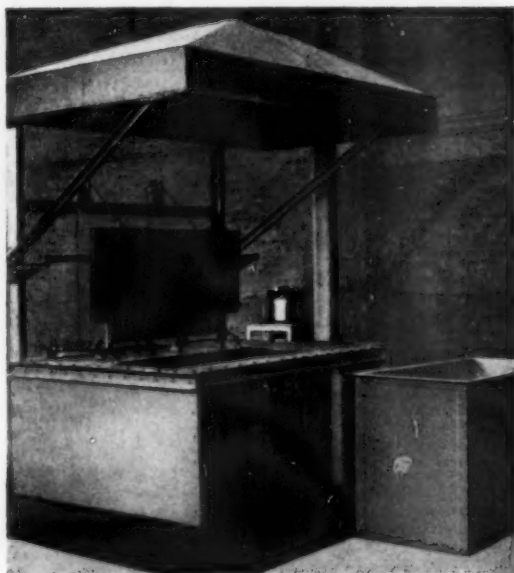
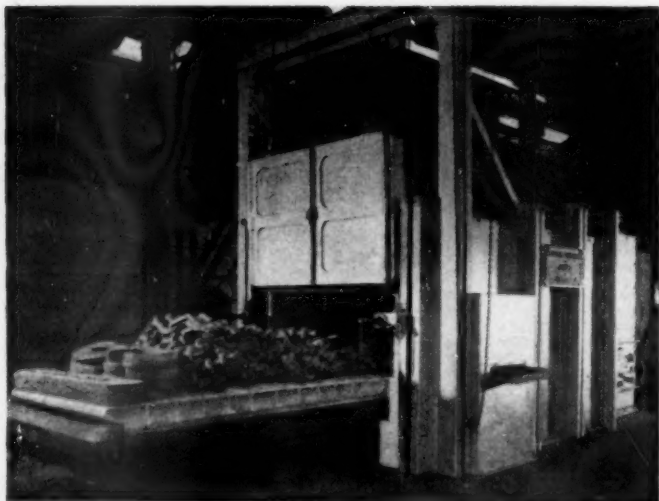
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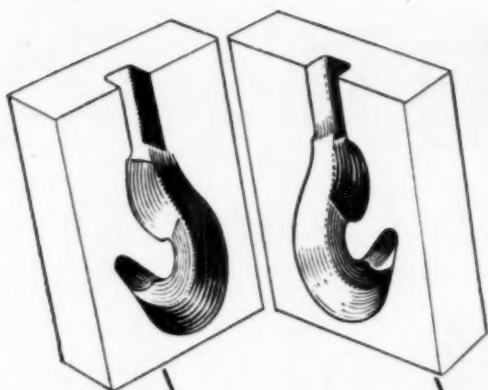
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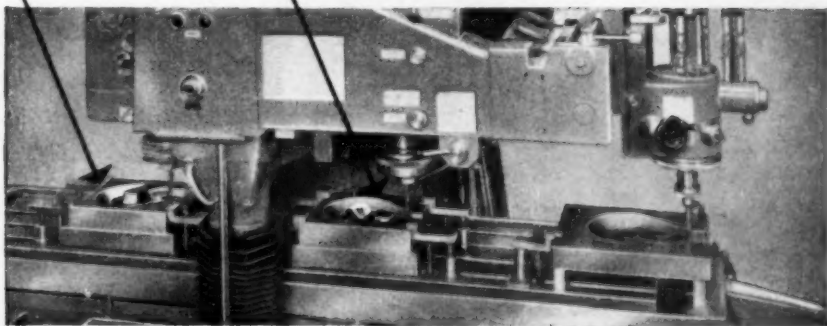
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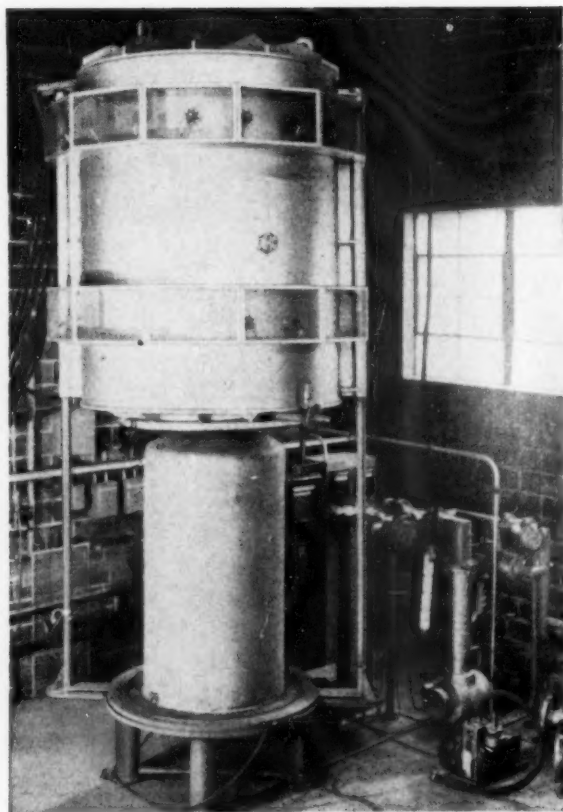
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December 1959

Vol 26, No 171

Metal treatment

and Drop Forging

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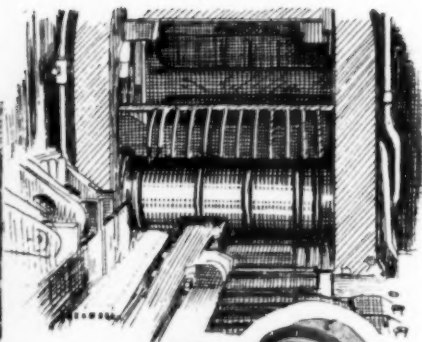
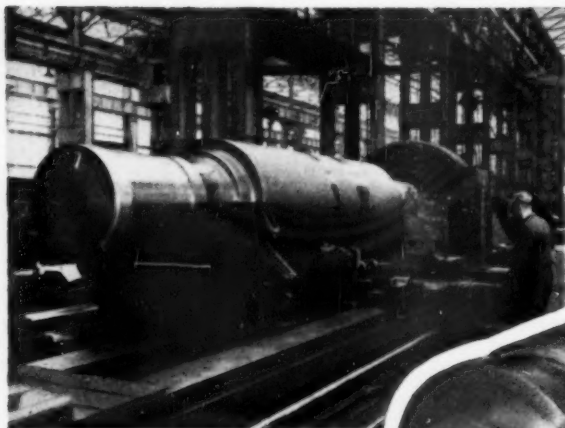
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Youth in industry

‘WHEN I was a lad, many’s the pay day I was kept waiting outside the Three Horseshoes for my money. That was the stamper’s way of putting me in my place. After I’d hung about for an hour or more, he’d condescend to come out and give me my wages.’ Thus speaks an old pensioner who was a trainee in the forge at the beginning of this century. In those days, a boy earned nine shillings and sixpence a week as a learner at the hammer, and worked 12 hours a day under conditions which now seem unbelievably hard. When we contrast this picture with the welfare and education-conscious attitude prevalent in industry today, it seems scarcely credible that only 50 years have passed. In the bad old days, the trade was learned the hard way, and the knowledge gained was a prized possession, whereas today every facility and inducement is offered to enable a youth to acquire his trade as painlessly as possible.

We must, however, beware of pontifical remarks about the ‘teenage problem.’ This problem seems to have been a source of argument for every generation throughout history, although it has undoubtedly made itself more insistent in recent years on account of the increased purchasing power of post-war youth. For the first time in our experience, young people in their first jobs are earning sufficient money to have become a consumer class in their own right and have even to some extent influenced manufacturing trends.

What effect will the emancipation of youth have on the future pattern of industry? Before attempting to answer such a question it is necessary to enquire to what extent the change has already affected the industrial apprentice. How does the young apprentice of today compare with his predecessor, and in what ways does he differ?

A small but interesting contribution to our knowledge is provided by a recent survey carried out by the Industrial Welfare Society among 400 apprentices, aged between 17½ and 22 years. These young men, who were attending a conference at Keble College, Oxford, came from all over Britain and were representative of a wide range of industries. They were each given a voluntary, anonymous questionnaire, which was carefully explained to them, and their answers analysed. Although these boys cannot be taken as an average cross-section of British apprenticeship, having in fact been chosen to attend the conference in many cases as a reward for good work, the answers are likely to be fairly widely applicable.

The first striking fact which emerges is the wide variety of their fathers’ occupations, only 20% being skilled industrial craftsmen. This may be a factor in only 40% of the boys belonging to a trade union; it would have been interesting to know how many of their fathers were union members. The improvement in social status of the craftsman is reflected in the fact that 60% of the boys believed they belonged to the middle or lower-middle classes, and 40% had received a secondary grammar school education. Nearly all lived at home and gave sums varying between £1 and £4 a week to their parents. Average personal expenditure ranged from £1 to £3 a week and most had money saved, nearly half of the boys having over £50 in savings.

These findings indicate that the present industrial apprentice has a much greater variety of family background than before and has greater financial freedom. One reason for this is undoubtedly the more attractive conditions in industry generally, and also perhaps the blurring of the old social distinction of the ‘white collar’ worker and ‘others.’ We can only hope that this latter distinction is not soon to be replaced by a distinction between ‘white coat’ worker and craftsman. It will be a great waste if industry’s insatiable demand for graduates ends by reducing opportunities of promotion to the promising boy who gains his experience as an apprentice.

Oscar Brandt

LAST MONTH, after a long and painful illness, Mr. D. J. O. Brandt died at the age of 40. He had been editor of METAL TREATMENT since the beginning of 1957, as well as metallurgical editor of *Iron and Coal Trades Review*. His activities in the metallurgical field were many and varied and his name is not likely to be soon forgotten. He was a strong and prolific writer on steelmaking and the steel industry, a broadcaster, and had lectured in many parts of the country and abroad. His book, 'The manufacture of iron and steel,' published by the English Universities Press, was widely acclaimed as a standard work and he was in the process of revising it when he died.

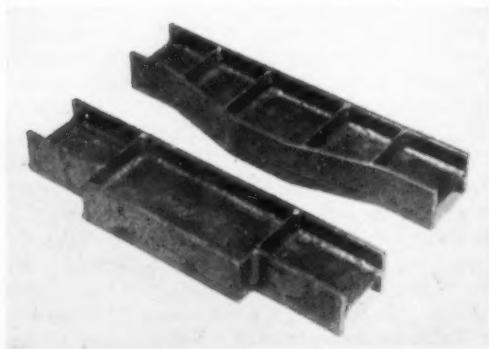
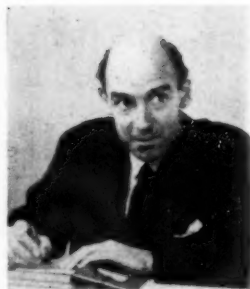
Born on Christmas Day, 1919, Brandt was educated at Clifton and studied metallurgy at the Royal School of Mines, which he left with a B.Sc. degree and the distinction of A.R.S.M. He was for a time with Murex Ltd., of Rainham (Essex), leaving in 1942 to join the Department of Tank Design of the Ministry of Supply.

He was engaged in that department until the end of the war on the development and testing of armour plate. He then went to John Miles & Partners (London) Ltd., consulting metallurgical engineers, with whom he remained until 1948, when he joined the British Iron and Steel Research Association as a senior scientific officer in the steel-making division. He left BISRA in 1955 to practise independently as a metallurgical consultant, largely concerned with the application of oxygen to steel-making. He was a Fellow of the Institution of Metallurgists and a member of the Iron and Steel Institute and the Institute of Metals.

Steelmaking, for Brandt, was really an art. Although by no means rejecting out of hand the results of laboratory experiment, he insisted firmly on the knowledge which could only be gained under actual steelmaking conditions. He had a great respect for the experience of the practical steelmaker who really cared about his job, and nothing in-

furiated him more than the indiscriminate application of the results of small-scale tests to production-size processes. As he was not a man to keep his ideas to himself, or to express them half-heartedly, it could not be expected that his opinions would please everybody. It can, however, truly be said that his criticisms were 'ways from conviction and not made with an eye to personal considerations. He had a real desire to see this country once more in the forefront of industrial progress, and never missed an opportunity of pointing at causes which he considered stood in the way of its realization. The keen sense of humour with which he balanced his technical preoccupations was perhaps only known to his friends.

Some of us had known Brandt much longer than the three years he had spent in these offices, but we shall all miss him very much and we offer our sympathy to his wife, son and two daughters.



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W. F. S. TAYLOR

The shaker-hearth furnace offers considerable advantages in dealing with small parts during hardening and tempering operations. Mr. Taylor, with the Furnace Division of Birlec Ltd., describes an installation at the Luddenden works of C. Lindley & Co. Ltd., where these furnaces are being used to deal with a throughput of about 14 tons of bolts and nuts per week

FURNACES THROUGH WHICH the work is passed by means of a shaking or vibrating hearth plate are rapidly gaining favour, particularly for the hardening and tempering of steel bolts and nuts.

The major advantage of the shaker-hearth furnace is that the hearth plate is enveloped in the furnace proper, and does not suffer the disadvantage of a conveyor belt which cools off after leaving the heating chamber. The hearth plate surface can be flat for such work as bolts or nuts, or may be fluted for handling pins, needles, etc.

This type of furnace was developed initially to deal with small parts which were found difficult to handle. Its popularity arises from a number of design features which have led collectively to a piece of equipment which is not only as efficient as it can be made, but is also easy to install and operate.

Shaker-hearth furnace design

Shaker-hearth furnaces can be designed to be heated by gas or electricity, but, for hardening operations, it is usual to employ an electric furnace, as accurate temperature control is somewhat easier, and it is convenient to fill the furnace chamber with a controlled atmosphere of pre-determined composition. If tempering is carried out in an electric furnace, especially where the bolts are quenched in oil, there is a tendency to encounter troubles due to sooting, which can be avoided by using gas firing; it is nevertheless usually desirable to degrease the work prior to treatment, so as to minimize the amount of smoke and fumes produced.

Due to the simplicity of the hearth plate and supports, the volume of the furnace chamber is kept down to a minimum, which allows for speedy purging, and minimizes the amount of atmosphere gas used. The rear or discharge end of the heating

chamber is closed and sealed by the oil quench which prevents access of air. The only exit for the furnace atmosphere is at the charging end, where its flow is limited by an adjustable shutter. Direct observation of the work just before discharge is provided by a sighting tube through the furnace wall.

To limit the splash of oil on quenching, the quench chute is fitted on two sides with horizontal slots through which oil is pumped to form opposing curtains which meet in the centre of the chute. These curtains are effective in absorbing the splash and preventing contamination of the element chamber. The slots are provided with clearing rakes, which can be operated from outside the furnace to remove possible obstructions. The curtain forms the entry point of the cooled oil to the quench tank, ensuring that fire risk is minimized and that the work is sufficiently chilled. The quench tank is fitted with its own tubular oil cooler located in the pit, which in turn is fed by town's water supply.

The furnace and quench tank combine to form a unit of clean outline, and the tank can be arranged to be either in line with or at right angles to the furnace centre line. The use of two right-angle layouts, forming a square, is sometimes particularly convenient from the operational standpoint in that it enables two furnaces to be fed at one point, and the quenched bolts to be discharged at another. It is also quite feasible to arrange the hardening and tempering furnaces with their quench tanks in line with one another with a degreasing plant in between for continuous production.

The quench tank conveyor can either be of the bucket type or the piano-hinge type, as indicated in fig. 1. The latter type has the advantage of avoiding any possibility of bolts swimming and jamming the

conveyor chains, but is rather more expensive than the former.

A single furnace can be supplied with a de-rating switch so as to be usable for both hardening and tempering where the total throughput is relatively low, but generally speaking it is preferred to employ a separate tempering furnace with specially designed air circulation.

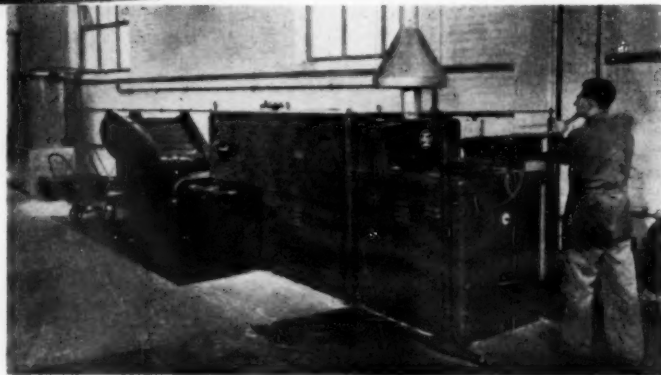
Lindley installation

The accompanying photographs show views of an electric-hardening furnace, and a gas-fired tempering furnace at the Luddenden works of C. Lindley



1 ABOVE Detail of the quench tank conveyor of the piano-hinge type used on the electric hardening furnace

2 RIGHT Electric shaker-hearth furnace used for hardening bolts and nuts. Rated at 40 kW., the furnace has a hearth plate of 18 in. width and is capable of a maximum output of 300 lb./h.



& Co. Ltd. These furnaces together are dealing with a total throughput of approximately 14 tons per week, working single shifts. The bolts dealt with are of varying grades of steel, from 0.1 carbon to high-tensile grades. The lower carbon steels are merely given a stress-relief treatment so as to yield a final strength of 28/35 tons tensile. The higher carbon grades 0.3-0.45 carbon are hardened and tempered to a final 45/55 tons tensile.

Lindley & Co. have fitted each of their furnaces with an automatic air-operated hopper-feed arrangement, impulsed by the hearth-plate timer, which can be shovel loaded, thus releasing the operator for other duties.

The hardening furnace is equipped with an exothermic gas generator for maintaining a protective atmosphere within the furnace chamber. The tempering furnace, since it is gas fired itself, generates an atmosphere which is suitable for the process, without necessitating an independent source.

Hardening furnace

The electric shaker-hearth furnace shown in fig. 2 has a hearth-plate width of 18 in., is rated at 40 kW., and is capable of a maximum output of 300 lb. h. of bolts up to $\frac{1}{2}$ in. diam. With larger diameter bolts, the heating-up time tends to increase to some extent, and the output is slightly reduced in consequence. Up to a maximum diameter of 1 in. by 6 in. long can, however, be dealt with without damage to threads.

The heating elements, which are accessible through the furnace top, are divided into two separately controlled zones, so that the heavy demand of the first portion of the hearth plate can be met without overheating the discharge point. A specially disposed element on the rear discharge wall ensures that bolts on the extreme end of the hearth plate do not cool off prior to quenching.

The conveyor arrangement of the quench ensures that bolts are not allowed to pile up under the chute, and any tendency to 'back tempering' is thereby eliminated. The shaker mechanism is air operated, and the speed of throughput is controlled by the rate of push as indicated on a timer dial.

Protective atmosphere for hardening furnace

The controlled atmosphere in the case of Lindley's installation is derived from town's gas in an exothermic generator of 300 cu. ft./h. capacity. For locations where no town's gas is available, a satisfactory atmosphere may be obtained from a similar generator, using bottled butane or propane. The exothermic atmosphere is generally satisfactory for hardening where a bright finish is not a necessity, and slight decarburization can be tolerated. Where freedom from decarburization is essential the endothermic type of atmosphere is recommended, and a different design of generator is required. In either case the combustion reactions are the same.

Table I illustrates the percentages of the main constituents of typical exothermic and endothermic atmospheres:

TABLE I Main constituents (%) of typical atmospheres

	Exothermic	Endothermic
H ₂	14	45-80
CO	12½	27-28
CO ₂	5½	0-1
CH ₄	4	2-4

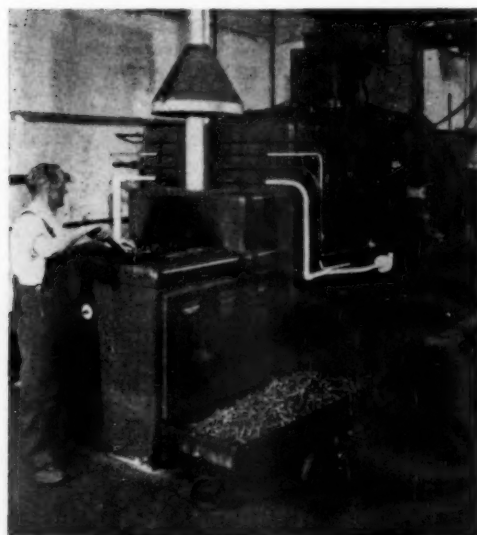
The tendency of the atmosphere to decarburize is mainly governed by the ratio of CO₂ to CO, which

reduces as the air gas combustion mixture is made richer. The limit to which this mixture can be enriched in the exothermic plant is slightly below two to one. Beyond this point the amount of heat generated by the combustion becomes too low to maintain the required temperature for reaction to take place. In an endothermic plant the air-gas mixture is passed through a heated catalyst chamber, which is maintained at combustion temperature by external heating elements. With this plant the CO₂ content can be reduced sufficiently low for the gas to be non-decarburizing to high-carbon steels.

The first cost of the endothermic plant is somewhat higher than that of the exothermic plant for the same amount of atmosphere gas produced. One 300-cu. ft./h. gas plant would feed one 12-in. and one 15-in. wide furnace. At Lindley's, the 300-cu. ft./h. atmosphere generator supplies a cast link belt conveyor furnace in addition to the electric shaker-hearth furnace.

Tempering furnace

The gas-fired tempering furnace illustrated in figs. 3 and 4 has a maximum operating temperature of 600°C. The hearth plate is 24 in. wide by 8 ft. heated length, there being actually two flanged plates side by side. As in the case of the electric furnace, the hearth plate is operated by air pressure and controlled from an electronic timer on the control panel. Two Keith Blackman air-blast injectors, one on each side of the furnace, are arranged to fire into a combustion pocket toward the charging



3 LEFT Charge end of the gas-fired tempering furnace at Lindley & Co., Luddenden, Halifax. Equipped with a 24 in. hearth plate, the furnace has a maximum operating temperature of 600°C.

4 BELOW Discharge end of gas-fired tempering furnace



end. A system of baffles protects the work from the direct action of the burning gases, products of which are circulated from the centre of the furnace to the ends and back again to the centre by a powerful paddle-type fan. The waste products and any oil vapour formed are vented from the charging opening to a flue pipe.

The fuel gas demand varies from 570 cu. ft. h. when on full flow to 350 cu. ft. h. on turndown. The air blower and gas governor gear are mounted underneath the furnace so as to be completely enclosed. Ample protection is provided in case of failure of gas or electricity supply. The gas and air valves controlling the burners are operated by a Kent indicating controller, whilst over-temperature protection is taken care of by a thermostat. This furnace, like the hardening unit, discharges into an oil-quench tank with its own cooling system, and the work is retrieved by an in-line piano-hinge-type conveyor. Total electric power demand of approximately 11 h.p. is required for the fan and drive motors, etc.

Running costs

18-in. electric hardening furnace:

When considering the quoted approximate running costs for this furnace, dealing with 300 lb. of bolts per hour, the following considerations should be taken into account:

- (1) The electrical consumption is quoted for continuous running and does not include stand-by losses.

- (2) Replacement costs are for the furnace only, since to include the atmosphere generator would give a false impression: in this particular installation not only does the generator supply the hardening furnace but it also feeds a cast link belt furnace at the same time.

Excluding labour	Per h. s. d.
Electricity—43 units at 1d.	3 7
Cooling water and compressed air	4
Town's gas for atmosphere supply	6
Replacements (hearth-plate elements, etc.)	9
	<hr/> 5 2

24-in. gas-fired tempering furnace:

When considering the quoted running costs for this unit, the gas consumption is based on an average figure of 460 cu. ft. h. at 6d. per 100 cu. ft.

Excluding labour	Per h. s. d.
Fuel gas	2 6
Cooling water and compressed air	4
Power for blowers, fan and quench tank . .	10
Replacements	6
	<hr/> 4 2

Acknowledgment is due to Lindley & Co., Luddenden, from whom certain of the foregoing information was obtained.

New techniques in forging

concluded from page 447

grids are marked on the specimen or on the interfaces of composite specimens. Grids are applied before working; deformation is determined by observing the distortion of the grid lines after working. Metal flow can be measured precisely by such methods. In other experiments, drilled holes are plugged with rods of different material, and the specimen is sectioned after forging to show movement of rods.

Other techniques are used; an interesting one for studying cold deformation is to observe the recrystallization behaviour after rolling. This is based on the well-known principle that the most highly worked material is the most easily recrystallized. Hardness traverses and other mechanical property studies have also been used to estimate the amount of cold work. In addition, plasticine models, X-ray methods, two-phase alloys, analysis of

internal flow from external shape and other techniques have been used.

Many studies have attempted to deal with die friction in a fundamental way. Also several studies of die wear have been made using radioactive tracer techniques.

The surface has only been scratched in studying fundamentals of the forging process. Nevertheless, progress has already been made. Much more should be done and will be done as time goes on.

Change of name

It is announced by Birlec Ltd. that, with effect from January 1, 1960, the company name will be changed to A.E.I.-Birlec Ltd. The change coincides with the final reorganization of the structure of the parent company, Associated Electrical Industries Ltd., into several product divisions. The internal organization of Birlec Ltd. will not be affected. The company will continue to operate the same way as in the past for the manufacture of heat-treatment furnaces, gas plants and adsorption dryers. The name of its associate company, Birlec-Efco (Melting) Ltd., will not be changed.

New techniques in forging

A review of recent developments

Some new forging techniques which are receiving attention in the U.S. were discussed in Metal Progress, August-September, 1959, by J. H. Jackson, manager, and H. B. Goodwin, consultant, metallurgy department, Battelle Memorial Institute, Columbus, Ohio. The following article is a slightly adapted version of their account

THERE ARE MANY new forging developments on the horizon. Some of them are unproven or even controversial, but all give evidence that there is no stagnation in the forging industry. Recent years have seen these important developments:

The counterblow hammer.

The 'impacter.'

The GFM 'precision forging' process.

The 'continuous grain flow' process.

Acceptance of roll forging.

'Cored forging.'

Multiple ram technique.

High-energy forming.

Aside from these new processes, there has been much progress in conventional techniques. Hammers and presses continue to become more efficient, and better diemaking methods have appeared.

The counterblow hammer

During the 1930's, the Germans introduced the counterblow hammer, and built about 350 of them to replace steam drop hammers. At that time, limited trials were made in the U.S. with unsatisfactory results. American technical teams, which went into Germany after the war, found the Germans had progressively developed larger and larger counterblow hammers for making very heavy forgings. When a large hammer was installed at the Ladish Co., a heated debate began concerning whether or not this type of hammer was adaptable to American forging practice.

The counterblow hammer overcomes some of the factors that limit the power of conventional steam drop hammers. The latter can be built to about a 45,000 to 50,000-lb. rating*, counterblow hammers which can do the work of a hammer with a 100,000-lb. rating have been built.

In the counterblow hammer, the large inertia mass needed in the anvil block is eliminated. The lower die is mounted on a movable ram which moves

counter to the upper ram and die. The two rams, synchronized by coupling systems, meet at the centre of their combined travel, where the work-piece is held. Because both rams are the same weight and moving at the same speed, when they strike, the force of the blow is not transmitted to the foundations.

In a conventional hammer, from 10 to 30% of the force of the blow may be lost through the anvil into the foundations. The heavier the anvil the less energy lost, but the greater the size and cost of the installation and foundations. Therefore, the anvil weight is a compromise. It is often around 18 to 20 times the hammer rating (anvil ratio) which means that the largest hammers require anvils weighing some 800,000 lb. With constant anvil ratio, the proportion of lost energy appears to increase as hammer size increases. This fact, coupled with increased manufacturing, transportation, and other difficulties associated with larger anvils, places a practical limit on the size of conventional hammers.

Another reason for limiting hammer size is the magnitude of earth shock and the distance which it travels. Both become so great that it is difficult to find locations where the hammer shock will not interfere with other operations. In addition, serious problems occur because oak fibres in the timbers (over concrete foundations) on which hammers are mounted break down. When this occurs, tilting of

*The rating of the conventional drop hammer is the 'falling weight' or weight of the reciprocating parts. Since steam pressure aids in striking the blow, the actual hammer energy is about double that of a board drop hammer of the same nominal rating. While there is no easy way to compare capacity of hammers and presses, a 12,000-ton hammer will make forgings that would require a 5,000-ton or larger press. Counterblow hammers are rated in ft.-lb.; dividing the counterblow hammer rating in ft.-lb. by 8.5 gives the approximate equivalent drop hammer rating in pounds. This is based on drop hammer efficiency of 80% and striking velocity of 26 ft. sec.

the anvil may result; this can, in turn, cause one-sided wear or breaking of the hammer guides.

The counterblow hammer is said to eliminate most of the difficulties. Furthermore, counterblow hammers forge the work equally on both sides; it is not necessary to turn the forging.

Critics point out that customary American practice is to forge the work progressively in several impressions in the same die, lifting the part by a tonghold and laying it in the appropriate impression in the bottom die. Because the bottom die moves, this practice cannot be followed with the counterblow hammer.

In contrast, European practice has customarily been to use the impression die hammer for final sizing only. Most of the preliminary shaping is done on other equipment—often flat die hammers. There are many large parts where progressive impressions are needed to make the stock flow properly, and it is questioned whether the counterblow hammer is suitable for any forging other than those simple enough to be made in single-impression dies. Operating speeds and possible mechanical difficulties are also criticized.

As yet, the counterblow hammer has not found any large place on the American scene. However, one U.S. company is now installing what will probably be the largest counterblow hammer ever constructed.

The impactor

In the fall of 1952, Chambersburg Engineering Co. announced 'impacting.' According to claims, this new process makes it possible to produce many types of parts automatically.

Essentially, impacting is forging carried out in mid-air. Two opposed horizontal impellers, run by compressed air or steam, carry the forging dies. Their strokes are timed by electronic controls so that the two rams always come together in the same plane of impact. For forging, hot or cold stock is suspended between the dies and struck on both sides simultaneously. In a more recent modification, a finger supporting the stock is retracted just as the impellers come together leaving stock unsupported in mid-air just before it is struck.

Models are built for flat die forging. The operator may hold the stock with tongs as in conventional air and steam hammer forging, or cranes, manipulators and stock positioning devices can also be used.

Advantages of the process are:

1. Shock and vibration are largely eliminated because the two opposing impellers have equal momentum. No heavy foundation or anvil is needed.

2. Metal is worked uniformly because the stock is struck equally from both sides.

3. Efficiency is increased; nearly all the energy is

absorbed in the workpiece. Less total energy is required than with other forging processes.

4. Contact between stock and dies lasts only a few thousandths of a second. This results in longer die life and easier forging because the piece is not chilled as much.

5. The working area may be readily enclosed and a protective atmosphere provided.

6. Mechanical positioning is more accurate; less stock is required in forging blanks. Mechanical handling is also safer.

7. Automatic heating, feeding, forging, and discharging of stock are easy to arrange.

The GFM 'precision forging' process

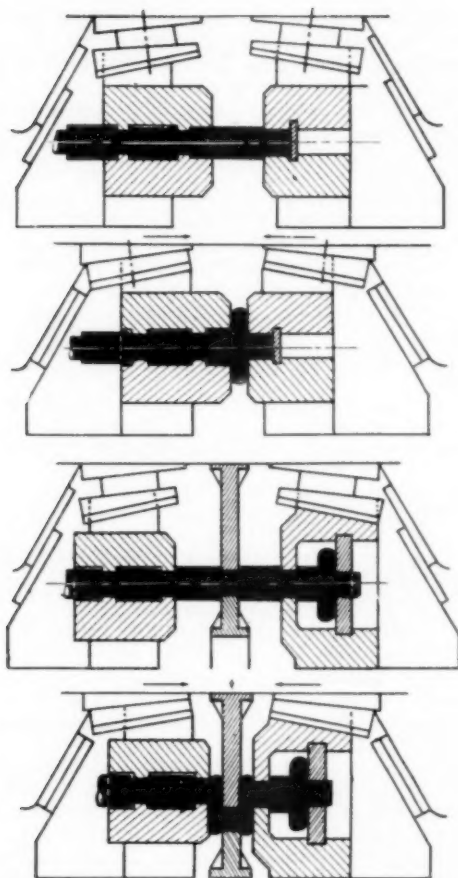
Brought to perfection in Europe since World War II, a new forging concept known variously as 'precision forging,' 'rotary forging,' or the 'GFM process' has recently been introduced in the U.S. The process got its start in wartime German experiments on cold forging the rifling into gun barrels.

In the basic machine, three, four or more hammers converge radially on the workpiece somewhat as they do in a rotary swaging machine. Equally spaced around the workpiece, they all strike it at the same time. The process differs from swaging in that the end-of-throw positions of the hammers are precisely controlled and can be varied during the forging process. In effect, each hammer is mounted on a solid connecting rod driven by an eccentric. Each eccentric is itself eccentrically mounted in a separate housing. By turning the housing, the entire hammer mechanism is moved inward or outward with respect to the central axis of the workpiece. If all housings are turned at once, all hammers move in or out together.

The outer shape of the forging (which can be cold or hot) comes from the shape and setting of the hammers. Hammer dies are generally simple in design and are easily changed. The workpiece is rotated to produce round shapes, but other cross sections may be produced without rotating the workpiece. The inside can be shaped by a suitable mandrel.

The workpiece is firmly held by a chucking head which feeds the work into the machine. Hammer settings and chucking head movement are positively controlled by a series of templets mounted on synchronized indexing drums. Thus, the forging cycle is usually completely automatic once the operator chucks the piece and pushes the starting button.

Vertical machines take stock up to 5 in. in diameter with forged lengths up to 48 in.; a horizontal machine which will forge 12-in. diameter stock in lengths up to 78 in. has been built. These machines can produce forces of 220 tons hammer



1 The continuous grain flow process. At the top, the part is ready to be forged. Next, the jaws come together to make the flange. In the third and bottom diagram, the throw is formed. Action continues until the crankshaft is finished

and operate at speeds of 600 strokes/min. An ingenious design prevents the forging forces from acting on the control system.

The two great advantages of the process are high precision and high speed. In regular production, work is finished to these tolerances:

- Hot ± 0.012 in. outside
- ± 0.004 in. inside (with mandrel)
- Cold ± 0.004 in. outside
- ± 0.0004 in. inside (with mandrel).

Curtiss-Wright has forged in 40 sec. a work-piece having seven outside dimensions and four inside diameters plus tapering joints. Rocket nozzles have been forged in 30 sec. Heat exchanger tubes, venturi tubes and artillery shells have also

been made by this process. Costs are often considerably below those of other forging methods.

The 'continuous grain flow' process

Development of the 'continuous grain flow' (or 'CGF') process began in the 1930's. Difficulties met in forging locomotive axles at *Acieries de la Marine*, Saint Chamond, France, led to its conception by M. Roederer, an official of the company, and parts of an experimental machine were built. Hidden during the German occupation, these were assembled after the liberation of France. Since the war, the process has been extensively developed in Europe.

This process is an interesting example of the special forging method devised to solve a particular problem. Its principles and advantages can be understood by describing its operation in producing heavy crankshafts. In the CGF process, crankshafts are formed, one throw at a time (from bar stock or preformed bar) in a special forging machine which is positioned in a conventional hydraulic press (fig. 1). The upper member of the machine is attached to the moving crosshead of the press, and is built so that one downward stroke forms one crank throw. When placed in the machine, the heated stock is gripped firmly in three places, the two journals and the crank pin. As the crosshead descends, the outer grips (mounted on sliding cranks) move inward. The vertical movement of the crosshead produces horizontal movement of the outer grips through an inclined plane arrangement. The stock is upset between the outer and centre grips. At a certain stage, the centre grip moves down as the outer grips continue to move inward. Upset material then forms two webs of the crank. Since they are not held in at the periphery, they form an elliptical shape by the natural flow of the metal.

With preformed bars used for larger cranks, no initial upsetting is needed, and the centre and outer grips start to move at the same time. After the first crank throw is formed, the piece is moved and the operation repeated as often as needed to form additional crank throws. Only the portion of the bar to be forged is heated.

The advantages of the CGF process for making crankshafts are:

1. The fibres in the final forging are oriented to give maximum strength to the part, being parallel to the axis in the journals and pins, and perpendicular to the axis in the webs.
2. The central axis of the final forging corresponds to the central axis of the ingot. Thus, any unsound metal, which is most likely to be in the ingot centre, winds up in the neutral axis of the forging.
3. Hot twisting, necessary after forging crank-

shafts in the conventional manner, is eliminated, since the various throws are initially formed in the correct angular relationship.

4. Metal is saved because much less has to be removed by machining. (One large shaft, formerly made from an 8-ton ingot, could be made from a 2½-ton ingot by the CGF process.)

5. There are fewer rejects.

Small crankshafts are drop forged, and there is some debate over the size at which it becomes cheaper to use the CGF process. So far as technical practicality is concerned, the processes overlap. Other large parts can be forged economically by adaptations of the method.

Critics have emphasized its high capital cost and mechanical complexity. Furthermore, once the machine is installed in a press it takes considerable time to reconvert for normal forging operations. They also point out that specially equipped horizontal presses can upset large flanges even better than the CGF equipment. However, for certain applications the process seems quite useful.

Roll forging

In roll forging, in contrast to conventional rolling, the metal is worked only part of each roll turn. Instead of being round, the rolls are flattened on one side, giving clearance space between them during part of their revolution.

Originally, the rolls turned continuously and had to be large in diameter because a large gap was needed to introduce the stock. When the clearance space appeared, the operator thrust the stock between the rolls. They gripped the stock, reduced it, and ejected it back to the operator. Because of the operator's position, forging rolls came to be called 'back rolls.'

About 1948, the machine was altered so that the rolls did not rotate continuously. Instead, they remain stationary in the 'open' position, and are started when a 'trip unit' is actuated by the stock as it enters the rolls. As an extra feature, these machines are usually provided with a foot pedal; this aids 'jogging' during setup. The stop-motion feature means that only a small section of the rolls needs to be notched for entry of the stock. Thus, most of the circumference is available to work the metal. Rolls with smaller diameters can be used, and larger reductions per pass are possible with a smaller, less expensive machine.

Like rolling mills, forging rolls may contain a series of passes (successively shallower grooves), the number depending on the total reduction desired. Each time the rolls revolve to the 'open' position, the stock is thrust back into the next pass. Either all or part of the stock can be reduced. If the latter, the reduced section may be anywhere along the bar.

These new stop-motion rolls have been widely used to rough out forging blanks intended for finishing in closed dies. Without this preliminary shaping it is very difficult to forge a piece with both wide and narrow sections from a blank of uniform cross section in closed dies. Excessive flash and trim losses result. If the blank is roll forged first, the metal is disturbed in about the right proportions, and only a little longitudinal metal movement is needed to fill in the dies during final forging.

Advantages over other forging methods are:

1. Long, slender sections, with or without cross-sectional variations, can be made easily.
2. Shock and vibration of hammer forging are eliminated.
3. Roll dies last much longer than most forging dies.
4. Scrap loss in flash and trimmed ends is reduced.
5. Production rates of presses or hammers are greatly increased by preliminary roll forging.

Cored forging

Originated in England for making brass plumbing fixtures (elbows, tees, crosses, and the like), this process has also been used to form a wide variety of parts from copper, aluminium, bronze, aluminium alloys, unalloyed titanium, and other materials.

Formerly, hollow or tubular components were machined from conventionally forged blanks. Since it is obviously more satisfactory to forge the hollow into the part, the cored forging process was developed. Briefly described, coring punches, one or more, are forced into the heated billet while it is held in closed and locked dies. The displaced metal flows out against the die surfaces, conforming to their shape, and the interior hollows are formed by the punches.

The main difference between cored and solid forging is in the way pressure is applied. In solid forging, pressure is exerted by closing the die halves, whereas in cored forging it is exerted by the coring punches. Cored forging is commonly carried out in mechanical presses, and split dies are frequently employed.

Complex parts are made by using several coring punches which may operate in different planes. Up to four cores in a single plane may be produced. Cores need not be round in cross section but may have any shape, and a short section at the end of any core may have a different (but smaller) shape than the rest of the core. Since coring punches must not be allowed to meet during forging, hollows are always blind ended. For such parts as plumbing fittings, punches can come close enough so that very little metal needs to be drilled out.

There are some design limitations. Core size must be proportionate to the piece—in other words, large enough so that the displaced metal will fill

the die opening. Minimum wall thickness is about 0.10 in. Advantages are:

1. Very close tolerance—accuracy to 0.005 in. is possible.
2. Substantial saving of metal—subsequent machining is minimized.
3. No draft required—forging may have parallel walls.
4. Complex shapes easily handled.
5. Excellent properties in the metal—this type of working produces ideal grain flow.
6. Elimination of porosity.
7. High production, low cost.
8. Excellent die life (for brass, up to 100,000 pressings with repolishing after every 15,000 pressings).

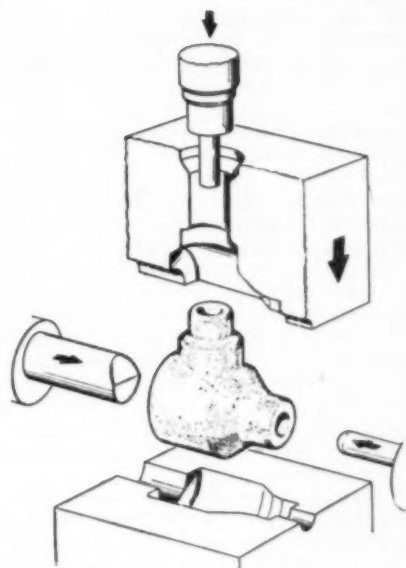
Multiple-ram technique

A unique method for making intricate forgings of heavy steel has been developed by Cameron Iron Works, Houston, Tex. Announced in the early 1950's, this process was developed mainly for making heavy oil-well fittings, but it is adaptable to a wide range of parts. Bosses, flanges and cavities, and shapes which include a number of angled holes and orifices, are easily formed so that little machining is required.

Key to the process is a huge multiple-ram hydraulic press. It incorporates an 11,000-ton main vertical ram, two opposed 6,000-ton horizontal side rams, and a 3,000-ton auxiliary ram for piercing and similar operations. For most forging, the side rams hold split dies together while the vertical ram forces metal into the die cavities in a confined upsetting operation. After a blocking operation by the main ram, the auxiliary piercing ram may force a relatively small punch into the hot metal. This displaces the metal under high pressure to all corners of the die cavity. When this auxiliary piercing ram is used in this way, the process is identical in principle to the cored forging process discussed in the previous section. The auxiliary ram and sometimes the side rams are also used for backward extrusion of metal around the rams to form certain parts. A special manipulator transfers the heated billet from the heating furnaces to the press.

Fig. 2 shows horizontal and vertical forging combined in one operation. Advantages are:

1. Intricate shapes, including hollow parts, can be made.
2. Little machining is needed.
3. Favourable grain flow produces excellent properties.
4. Operation is economical.



2 Schematic diagram of the production of a steam turbine interceptor valve by a multiple-ram forge

High-energy forming

In the past two or three years, explosive forming and other processes which use high deformation rates have attracted attention. So far, most studies have involved cold forming methods for sheets and plates, though a little work has been done on high-velocity hot forming. So many claims and counter-claims have been made for explosive forming that it is difficult as yet to assess the merits of the process. As an example, many investigators claim that metals flow like liquids at extremely high deformation rates. Consequently, less total energy and lower loads are needed for a given amount of deformation. It has been said that metals take the desired shape 'before they have time to resist.'

Explosive forming is being developed quite extensively by the aircraft builders because it offers much promise in forming large parts from high-strength sheet. Energy is supplied by explosives, or gas at high pressure. One of the attractive features is low equipment cost. Some methods need nothing more than a tank big enough to hold the die and blank. Only a female die is required; the blast forces the metal into it.

There is probably an optimum deformation rate for each operation and for each metal which will have to be established through research. One problem that is causing some trouble is the maintenance of thickness tolerances.

Metals that have been formed successfully

include carbon, alloy and stainless steels, aluminum alloys (both annealed and hardened) and titanium. 'Spring back' is virtually eliminated in materials that are explosive-formed; this is an added advantage.

A novel system of high-velocity forming, known as the 'Dynapak' process, was exhibited at the 1958 National Metal Congress in Cleveland by the Hyge-Convaiv Div. of General Dynamics Corp.

The machine operates through differential gas pressure on two sides of a piston in a closed cylinder. The forging ram, equipped with conventional dies, is attached to the piston. At the instant before the piston starts its stroke, low-pressure gas acting on a wide area on one side of the piston balances gas at much higher pressure but acting on a smaller area on the other side of the piston. On the high-pressure side, the piston rests against an orifice plate equipped with an O-ring seal; this prevents the high-pressure gas from exerting pressure on the entire piston area.

Gas pressure increases slowly on the high-pressure side. Finally, the equilibrium is upset. The piston moves away from the orifice plate, and the seal opens. Instantly the entire bottom area of the piston is exposed to the high-pressure gas. Since the pressure on the high-pressure side is many times that on the low-pressure side, the piston moves exceedingly rapidly—about 400 ft./sec. Travel rate can be controlled by tapered metering pins which are attached to the high-pressure side of the piston and project through the orifice. Machines with 12-in. and 24-in. strokes and energy outputs ranging up to 360,000 ft.-lb./stroke are offered.

Other forging developments

While these new forging techniques were being devised, there was also progress in traditional forging methods. Not only have hammers and presses increased in efficiency, but methods for making dies have become almost automatic.

At first glance, a modern steam drop hammer looks little different than the hammers of 100 years ago. This is also true of mechanical and hydraulic presses. All of them, however, are many times more productive than earlier models. One cause for this has been the trend towards larger equipment. However, efficiency has also increased. Modern hammers and presses are much more productive than early models of the same nominal rating. For example, the 2,000-lb. (usual nominal rating based on weight of falling parts) steam drop hammer of 1846 struck a 4,500 ft.-lb. blow; with an anvil ratio of 5 to 1, forging efficiency was 5%, and the hammer produced 100 lb./h. of low-carbon steel forgings.

In contrast, a modern hammer of the same 2,000-

lb. nominal rating strikes a 27,000-ft.-lb. blow at a forging efficiency of 80%. It produces 650 lb. of low-carbon steel forgings every hour. The anvil ratio is 20 to 1, and the percentage availability is 90% (as opposed to 50% for the 1846 model). With the larger equipment being used, average tonnage production per man-hour today is 25 to 30 times what it was 40 years ago.

There have been three major improvements in the steam drop hammer since its conception by England's Nasmyth in 1838. First came impression dies, accurately machined to shape; these were devised by American firearm manufacturers at about the time of the Civil War. Until then, most forging had been done with flat dies, or occasionally with very crude impression dies. The second major advance was the advent of the double-acting steam hammer in Midvale, Pa., in 1888. In this, steam was used not only to lift the ram, but to exert additional force on the downward stroke. As the third major improvement, a much better arrangement for steam valves was invented in 1933.

Starting in the early 1920's, the high-speed forging press was gradually developed to be useful for closed-die forging. Older presses, designed for other purposes, were too slow and not rigid enough for this. Modern presses have been important in increasing forging productivity. A 2,000-ton mechanical forging press will duplicate forgings produced on 4,000-lb. steam and 5,000-lb. board hammers.

In 1958, a fully automatic 2,500-ton mechanical press, built by the Erie Foundry Co., was announced. In trials one man produced 1,200 crawler track links/h. on this machine; this was in contrast to 275 links/h. formerly produced by three men on three hand-fed presses. Heating, feeding, forging, and delivery of the finished forgings could be accomplished automatically without assistance from the operator.

The upset forging machine developed in the 1880's has become larger, faster, more powerful and more rigid.

There is not space here to review the hundreds of minor improvements which have increased the productivity of these various machines.

Making dies automatically

Diemaking was originally a form of sculpture in hard metal. Excess metal was literally hacked out by hand, and machines could do little of the work. Gradually, tools especially designed for machining die cavities were evolved, until skilled machinists could do practically everything but the final dressing. In the early 1900's, automobiles, farm machinery, and other equipment began to be mass produced. The need for hundreds of thousands of identical forged parts gave rise to a

similar need for many sets of identical forging dies. This led naturally to the conception of machines which would automatically duplicate a given die impression over and over without a human operator. Gradual progress toward this goal has been going on ever since.

The first development was the tracer-controlled die-sinking machine. First, an accurate model (plastic, wood or metal) of the die impression is made. The tracer on the machine scans the model and guides the cutter to duplicate the impression in the model in the die block being machined. The tracer and cutter move together and must be equally accurate. The first machines were controlled mechanically and did little but rough out the impression.

About 1900, the Keller Mechanical Engineering Corp. (now part of Pratt and Whitney, Inc.) built the first mechanically-controlled automatic die-sinking machines. By 1920, the electrical tracer-controlled machine had been designed.

In 1935, Cincinnati Milling Machine Co. introduced a die-sinking machine which was hydraulically controlled. This machine combined automatic depth control with automatic 360° profile tracing in a horizontal plane. All movements (longitudinal, transverse and vertical) were controlled from a single tracer finger.

Today, many machine types are available. There are combinations in which two separate tracers are employed simultaneously with two separate masters, and machines which use templates rather than full masters. For simpler dies, many machines only control some of the machine movements automatically.

Many improvements have also been made in hand-operated die-sinking machines. They have become faster, more powerful, more rigid, and more accurate. Semi-automatic controls have been added so that certain machine movements can be repeated automatically.

New control methods

With the recent appearance of electronic computers and allied techniques, new control methods have come into the picture for automatic machining of metals. In 'numerically controlled' systems, punched cards, magnetic tape, punched paper tape or the like replace the model. Numerical control begins with a command (coded as numbers on tape or card) to move a machine member or to start or stop some operation. These control systems use 'feedback.' That is, some type of measuring system determines the exact position of the machine members at all times and feeds this information back to the control system.† Then the system compares input instructions with feedback data and makes corrections if needed.

So far, relatively little work has been done to adapt numerical control to die sinking. Wyman Gordon Co. has an experimental contract with the Air Force to evaluate numerical control versus tracer control for making forging dies. According to them, numerical control looks extremely good for two-dimensional control, but needs more work for three-dimensional control. At present, it takes longer to programme a numerically controlled machine than to prepare a model for tracer control, but numerical control provides greater accuracy and speed for the machining operation. Speed is higher because, through proper programming, optimum feed rates and machine speeds can be used at all times. There is hope that programming time can be cut drastically as trained operators become available and as 'libraries' of programmes are built up for standard shape elements. Maintenance, a headache at first, is now said to be under control.

There is little question but that all the techniques for numerically controlled diemaking are available. Only economics—mainly cost of programmes versus cost of models—will determine whether or not numerical control will come into widespread use.

Perhaps the most significant development of all is the research into fundamentals of the forging process itself. Though studies are only beginning, some work has already been done on:

1. The effect of impact and pressure on properties of metal.
 2. Metal flow in the plastic state (and the variables that affect it).
 3. Studies of die friction, die wear, and lubricants.
- These are examples only; the list is by no means as long as it could be.

With regard to the first item, we know that high pressure or impact greatly improves metal properties even in the absence of measurable metal flow.

Fundamental studies of metal flow have been approached from two points of view. The mathematical approach has been taken to determine the geometry of metal flow in relation to the stress system. However, many such studies have considered plastic metal flow in general, rather than any specific working process such as forging. The second approach is the attempt by metal physicists to determine the plastic properties of a metal from its atomic structure.

Numerous experimental techniques have been used to study metal flow. As one example, reference

†In cybernetic language, the machine has 'closed loop control'—it is self-correcting. (Hand-operated machines have 'open loop' control; feedback is provided by a human operator who measures the output—with micro-meters, for example—compares it to a standard and adjusts the machine accordingly.)



Société Française de Métallurgie

Autumn meeting, 1959

Metallurgists from many countries, including the U.S.S.R., met in Paris recently to take part in the annual autumn meeting of the Société Française de Métallurgie. A full week of meetings and discussions had as an underlying theme the behaviour of gases in metals and their detection. The full text of the papers given at the conference will eventually be published by the 'Revue de Métallurgie' and we give below summaries of some of the contributions. The opening address on the influence of additions to the carbon activity of liquid iron alloys was given by Prof. Dr.-Ing. Dr.-Ing. e.h. Hermann Schenck, president of the Verein Deutscher Eisenhüttenleute, who was presented with the Grande Médaille Fl. Osmond of the Society at this conference. Great Britain had the honour of receiving the other medal presented—the Médaille Sainte-Claire Deville going to Dr. Leonard Bessemer Pfeil, O.B.E., A.R.S.M., F.I.M., F.R.S., managing director, research and technical, the Mond Nickel Co. Ltd. We were glad to have the opportunity of witnessing this recognition of Dr. Pfeil's work by French metallurgists.

TOP Prof. Schenck receives the society's medal from the president, M. Paul Bastien

MIDDLE Presentation by the president to Dr. Pfeil

BOTTOM Prof. A. Scortecchi, director of the Instituto Siderurgico Finsider, who delivered last year's inaugural lecture, in conversation with Prof. Dr. h.c. A. M. Portevin

The heterogeneity of large forging ingots

THIS INVESTIGATION into the heterogeneity of large forging ingots, by C. Roques, P. Martin, Ch. Dubois and P. Bastien (Le Creusot), was originally begun by the Schneider Works at Le Creusot and then continued by a special committee set up by IRSID.

Some studies have already been published on this subject but have been mostly based on a detailed examination of a small number of ingots. It seemed a good plan to try and find a picture of the heterogeneity of large forging ingots based on inspection, limited to the essential features but carried out on a sufficiently large number of ingots to allow of statistical analysis of the results. For that reason a total number of 150 ingots, with individual weights ranging from 7-150 m. tons, has been examined.

It has been possible to establish that the total segregation of a given element (that is the range between maximum and minimum contents) is appreciably proportional to the content of the element. There is, then, a basis for expressing segregation as a relative value—proportion of segregation. It was also shown that the rates of segregation of different elements follow similar laws. In particular, for a given ingot, the size of main segregation of impurities and of the alloying elements is proportional to that of carbon. Results are given for the following elements: S, P, As, N, Si, Mn, Ni, Cr, Mo. Consideration was given to establishing the shape and the distribution of segregations in the mass of the ingot. Note was also taken of the extent of the axial zone containing local segregations of straight V shape and it was established that, in a certain number of ingots, loosenings (micro-holes and micro-cracks) usually accompanied these segregations in straight Vs.

The following conclusions have been drawn:

(a) In the field of variations in steel-making factors which have been studied, no factor other than the tonnage of the ingots has had any significant effect on the proportion of segregation of carbon and of the various elements mentioned above.

(b) Distribution of segregations is a function of the weight of ingot. In particular, the distance along the axis of the zone affected by negative segregation is relatively less in the case of large ingots.

(c) On the other hand, the extent of the axial zone affected by segregation in straight Vs and by loosened structure is not in relation to the weight of the ingot. It appears to be dependent on composition, particularly on the carbon and sulphur contents, and on casting conditions, particularly temperature.

A certain number of indications have also been noted as regards the distribution of oxygen, in the form of oxide inclusions, and of hydrogen. It has been shown that the laws governing segregation of

these two elements are distinct from those which apply for the whole of the other elements taken into consideration.

Steels with and without vanadium for forging

The object of this investigation by G. Delbart and M. Jaspard (St. Germain-en-Laye) was to determine the possibilities of improving, by the addition of vanadium, the mechanical properties of heat-treated steels for forging. The results already obtained by other investigators deal more especially with small pieces (tensile and shock test-pieces) and, so far as is known, there are few results on the influence of V in the case of large-size forgings.

It is known that, when properly put into solution during austenitization, vanadium allows of grain refinement being obtained, on the one hand, and of increased resistance to softening during reheating being obtained on the other hand. One of the problems to which special interest was attached was to find out to what degree the addition of V would allow of higher temperatures being used in reheating large forgings while retaining the same mechanical characteristics.

Industrial research has been done on several grades of steel: (a) carbon steel (with 0.038% V, and without V); (b) Cr-Mo steel, grade 35 CD4 (with additions of 0.053% and 0.287% V; and without V [35 CD4: C 30.39, Cr 0.81.2, Mo 0.15.30]); (c) Cr-Ni-Mo steel (grades 30 CD12, 30 CND8, 30 CND12 and 30 NCD11, with additions of 0.038-0.08% V; and without V).

In order to ensure good putting into solution of the V in steel 35 CD4 with 0.287% V, the temperature of austenitization for this steel was raised to 900°C. Systematic study was made of the quenchability of these various grades, of grain growth, and of the influence of V on transformation points and of the kinetics of changes under isothermic and anisothermic conditions.

The mechanical properties, taken longitudinally (and transversely for large sections), have been ascertained on 5-240-mm. ($\frac{1}{8}$ -9 $\frac{1}{2}$ -in.) dia. sizes, after quenching and tempering in the working range (550-650°C.).

The results obtained can be summarized as follows:

(a) *Carbon steels, treated* The addition of 0.038% V does not seem to affect the hardenability. However, in a general way, V lifts the elasticity/tensile ratio and reduces softening by tempering. For small diameter bars (5 mm.), with fully martensitic structure after quenching, V raises the tensile and elasticity, without appreciably lowering the other characteristics. But for sizes above 15 mm. ($\frac{5}{8}$ in.) (partial hardening) V does not make any appreciable change.

(b) *Cr-Mo steels (35 CD4, with and without V)*

The influence of vanadium on the properties of a 35 CD4 steel has proved very interesting for sizes up to 200 mm. (8 in.) dia., both in the normalized-tempered and in the quenched-tempered conditions.

In general, the tensile and the El/T ratio are appreciably increased, even after annealing followed by slow cooling. The addition of 0.287% V produces a very great refinement in structure. The effect of V in this amount is so marked that the same mechanical properties, taken transversely, are obtained on 8-in. rounds of steel without vanadium, hardened and tempered at 550°C., as on a bar of the same diameter of a steel with 0.287% V, normalized and reheated at 650°C. The impact strength in particular is not reduced.

The addition of V allows of the tempering of forgings to be raised to higher temperatures. Moreover, with vanadium steel, it is possible to provide for simple normalization followed by reheating to achieve the same properties as with quenching and tempering of a steel without vanadium. This is of special interest in the case of parts which cannot be quenched.

(c) *Ni-Cr-Mo steels (with or without vanadium)* These are high-quenchable steels with which V shows no effect on hardenability. Still, the addition of V lifts the tensile and the El/T ratio fairly noticeably after reheating between 550 and 650°C. For these steels, the minimum effective V content seems to be about 0.04%.

Tests of a more fundamental nature are being continued on carbon steels and on Cr-Mo steels containing 0-1% vanadium and coming from the same master-cast.

New ferritic steel for steam tubings and superheaters

L. Gottignies and M. Caubo (Brussels) gave a paper on a new steel for tubes and superheaters. The 2.25% Cr-1% Mo steel, which has been generally used in power-houses up to a metal temperature of 575°C., reaches its limit of service when the rise in thermal output requires a rise above that temperature. This demands the use of austenitic steels. The Belgian committee for the study of flow of metals at high temperatures, before deciding on this solution and with the object of saving in cost, went into the question of extending, as far as possible, the use of low-alloy ferritic steels.

Investigations were directed on the line of trying to get structural states favourable to heat resistance, and the following method has been pursued: (1) Additions of elements leading to the formation of carbides by slow evolution at service temperature; (2) heat treatments such that favourable structures would be obtained (initial precipitation of a large number of very small precipitates).

The choice of a steel for steam tubes has to take

into consideration quality requirements which are sometimes contradictory one of another, principally, resistance to fracture by long-term flow, ductility, forgeability, weldability, not forgetting the heat treatment, which must be industrially possible. All these various properties have been systematically studied with a view to getting a better formula of ferritic steel.

In the class of ferritic steels resisting oxidation, chrome is the chief alloying element to be considered. Two zones were studied, one ranging from 0.5-3% and the other from 8-12%. Improvement in the former range was first dealt with. As for the other alloying elements, chief consideration from the point of view of resistance to flow had to be given to molybdenum, vanadium and tungsten.

When the analysis was settled, two kinds of heat treatment were visualized: (1) A dual treatment consisting of austenitization, rapid cooling in air and reheating resulted in structural hardening of the steel. This treatment can be carried out on an industrial scale for superheater tubes, cooled one by one. (2) This treatment was austenitization followed by slow cooling in free air. This gave a more developed structural condition than the first one, and, consequently, was a little less resistant to heat. This treatment is similar to that for cooling large-size tubing in free air.

The steel, thus developed, has satisfactory properties for working and shaping, either hot or cold. With hot working, saving can be made by reductions in metal thickness, in comparison with steels now being used. If the same thickness is used, higher temperatures and pressures can be attained in service. This improved resistance is only slightly affected adversely by welding.

Research work and tests on this steel have included more than 600,000 h. of flow and fracture tests. Tests have been for as long as 20,000 and 50,000 h.

Users and inspection control bodies in Belgium, interested by the formula put forward by the committee, have joined in getting it put into industrial service. The actual use of the steel in industry, from the point of view of safety, is protected by laboratory controls by demanding test-pieces cut from the tube assemblies to be in their hands 10,000 h. in advance, the samples being taken both from the basis metal and also from the mixed and homogeneous welded tube assemblies. Results obtained from these controls confirm all expectations based on the results of the research work.

Forgeability of ferritic steels for superheater tubes

By means of torsion tests at various temperatures, it has been shown by O.-L. Bihet and M. Caubo (Liège) that the forgeability of a 9% Cr steel, con-

taining various other additional elements, is greatly influenced by its structure at forging temperature.

The structure which gives best forgeability is one which is completely ferritic at forging temperature. However, certain bi-phase structures also lead to good forgeability, being in every case superior to the values obtained for fully austenitic structures.

It is, therefore, possible to obtain in the grade of steel under consideration a ferritic structure or a slightly bi-phase steel at 1,250°C., by balancing the added elements (alphanogenous and gammagenous) in a suitable manner. It is then equally possible to obtain satisfactory forgeability from such casts. A substantial gain in forgeability can also be obtained by forging within a temperature range very carefully determined.

Gases in metals

At the instigation of M. Calmettes, of the Société des Forges et Ateliers du Creusot, the Laboratory Engineers' Committee of the French Iron and Steel Technical Association called together representatives of steel laboratories actively engaged on the analysis of gases in ferrous metals. The general idea, state Miss M. Hanin and E. Jaudon, was to standardize the methods of analysing gases in metals so that the results would be comparable.

The estimation of hydrogen was first considered, since it is in this connection that difficulties arising from differences in operating methods had been very noticeable. There was all the more reason to go into such questions on a national basis since the Centre National de Recherches Métallurgiques, Liège Section, was proposing to arrange an international committee on the same subject.

Comparative tests have been made with sample-taking and conserving under mercury, under carbonic-acid snow and acetone, and these have shown that the standard method in France, called the 'notched pencil' method, is worthy of the confidence placed in it. In order to find the reason for the divergencies in the results observed from identical samplings, taken under the same conditions, it has been necessary to go into the question of the manufacture and calibration of the glass 'dry gauge,' and a MacLeod type of gauge, which can be used without correction on physical analysers, has been approved.

As regards oxygen in particular, the preponderant influence of the sample-taking of the molten steel on the scatter of results has been shown.

Proposals for defining what should be understood by the expression 'soluble nitrogen' have been submitted to the International Commission, as also for 'insoluble nitrogen' and 'dissolved nitrogen,' according to the points of view of the metal physicist and the chemist, and an inventory has been drawn

up of the various methods of analysing for nitrogen, both by purely physical as well as chemical means. A combination of these methods will probably be necessary to reconcile these points of view.

The role of the vacuum technique to metallurgy

The use of the vacuum in metallurgy is fairly recent, although many physico-chemical laws, in which it comes in, have been known for a very long time. This, according to D. A. Degras (Paris), is essentially due to the relatively slow development of the vacuum technique on the one hand and also to the advances made by metallurgists in respect of the requirements generally formulated a short time ago.

At low pressure, metals can be suitably de-gassed. It is indeed known that occluded gases can appreciably change their physical and mechanical properties. Hydrogen is soluble in copper, silver, chrome, iron, nickel, aluminium, platinum, etc., and its solubility varies as the square root of the pressure of the gas and as the temperature of the metal. With elements of noble ores, and of other metals, it forms pseudo-hydrides, whereas with alkaline metals and alkaline ores, it forms true compounds. The formation of floccules is linked with solubility, and this can vary with the different phases of the metal when its temperature varies. Nitrogen gives fairly often metallic nitrides, and carbon monoxide is capable of forming combinations of the same type. As for oxygen, its very great chemical reactivity allows of oxides being formed alongside solutions.

Working of metals under low-pressure also allows of physico-chemical equilibria displacement and this can be studied starting from Le Chatelier's mass effect law, when one or many gaseous phases are present. Low-pressure distillation is also used in metallurgy for refining metals or separating out alloy constituents, this being done, for example, with magnesium, lithium, calcium, aluminium and mercury.

Working in vacuum is equivalent to working protected from the contaminating agents in the atmosphere. From this angle, numerous methods devised to protect operations from the oxidizing action of the air can be enumerated: such as powder metallurgy, welding, transformer sheet annealing. Finally, additions to special alloys are sometimes easier to control *in vacuo* than in atmospheric air. This is particularly true for additions of titanium and aluminium, which are strongly oxidizable.

Metallurgical plant for working in vacuum includes melting furnaces and heat-treatment baths. Working of metals or alloys under low pressure leads to melting in various types of furnaces, such as resistance furnaces, induction furnaces, arc

furnaces, electronic furnaces. The first three types of furnace are well known as working at atmospheric pressure, but it can be conceived that, by adding a set of pumps, and making the installation air-tight, a low-pressure furnace is produced. Actually, the problem is not so simple. Immediately pressures lower than a few millimetres of Hg are required, the choice of materials, forming the walls surrounding the area to be evacuated, becomes specially important. The amounts of gas given off by the metal require large output pumps, which are costly, and it is important to limit as much as possible the parasite gases given off by crucibles, walls, inside controls, etc. The technology of vacuum furnaces therefore tends to move away from that of atmospheric-pressure furnaces, all the more so as the heat losses themselves arise essentially from radiation, for which reason reflecting screens are often used, when possible and desirable, and ordinary insulators are almost excluded.

Treatment baths are generally fitted with low-temperature furnaces (300–1,000 C.) with resistance heating. They are used for heat treating the new metals such as uranium as well as for alloy steels and irons such as transformer sheets. A furnace has been made to take 20 tons of metal transformer sheets.

A short description is given of some French and foreign plants for the treatment of ferrous metals, uranium, titanium, aluminium, copper, silver, etc. Some figures are also given of the output expansion of vacuum-produced metals in the U.S.A., particularly for steel.

Amongst the practical results achieved in the iron and steel industry, attention is drawn to the elimination of cracks in alloy steels, the possibility of increasing mechanical working with the same margin of safety, the improved resistance of certain stainless steels to corrosion, the improvement of magnetic qualities and of castability and an extreme degree of purity of iron for laboratory work.

Determination of oxygen and hydrogen in steel

The bearer-gas analysis method was discussed by C. E. A. Shanahan (Whitchurch, Gt. Britain).

The methods usually employed for determining total oxygen and total hydrogen in steel make use of extraction in vacuum at high temperature. The oxygen content is determined by melting the steel sample in the presence of carbon so that all the oxygen forms carbon monoxide which is drawn off by the vacuum pumps at the same time as nitrogen and hydrogen. The amount of CO can be measured by determining the total volume of the gases and by analysing them. The gases coming from the furnace can be treated hot by a mixture of copper oxide/iron oxide (Arneil reagent) so as to change the CO com-

pletely into CO₂, which is easily absorbed by cooling or by chemical combination with, for example, soda asbestos.

Although theoretically hydrogen estimation can be done at the same time as oxygen determination, it is preferable in practice to deal with the hydrogen separately. This is due to the fact that all the hydrogen may be taken out of the steel by extraction under vacuum at temperatures around 650 C., well below the melting points of steels. The body of the furnace is, therefore, much simpler in design than the one necessary for oxygen determination and, moreover, the analysis of the total gases being studied includes 90–95% hydrogen which eliminates the need of a gas analysis in routine work.

In spite of the importance of the oxygen and hydrogen contents in steel, works laboratories generally prefer to avoid doing these tests. This arises from the high cost and the fragile nature of the equipment required and from the need for personnel trained in the technique of high-vacuum work. The author and his colleagues have, therefore, developed methods of determining the total oxygen and hydrogen contents which do not require extensive vacuum apparatus, or delicate glass-work or specially trained technicians. These new methods are considered as being easy to use in steelworks laboratories.

Theoretically it should be possible to use an inert bearer gas in place of vacuum for extracting gas from steel. The presence of molecules of bearer gas may slightly reduce the speed of evolution of CO or H but it does not prevent total final extraction. Such a method can be used at a pressure approximately equal to atmospheric pressure, and this avoids the use of vacuum pumps and allows of rubber joints being used to reduce the extent of slight leaks.

The final process developed for oxygen involves melting of the sample of steel at about 1,750°C. in a graphite crucible in a current of argon or purified nitrogen at 300 c.c./min. The gas carries the CO through a furnace containing Arneil reagent at 550 C., where the transformation of the CO into CO₂ takes place. The oxygenized sulphur compounds and moisture are extracted and the CO₂ content is determined by absorption in soda-asbestos. As one might expect, the gas contents are higher with these simpler tests than with vacuum equipment but their consistency over a series of tests allows of the necessary corrections being applied. An oxygen analysis can be done in 15 min. to a margin of 0.0016%. It is particularly easy to insert samples in the apparatus during working, which is an important advantage in running analyses in a works.

The bearer-gas process in determining hydrogen involves heating the sample at about 650°C. in a

silica combustion tube, through which the purified nitrogen flows at a speed of 2 l. h. (2,000 c.c.). Hydrogen freed from the steel is carried by the nitrogen first, through a tube containing Arneil reagent at 550-600°C., where the hydrogen is quantitatively changed into water; and then, into anhydrous methanol. Complete absorption of the steam is obtained and titration is periodically done with the Karl Fischer reagent, using the 'final stop point' test, which corresponds to a sudden change in potential between two platinum electrodes plunged into the titrated solution. The process has been carefully tested in such features as contents from blank tests, optimum flow of bearer gas, and quantitative change of hydrogen into water by the Arneil reagent.

Information about the precision of the process for determining hydrogen has been gained by introducing precise known volumes of hydrogen into the bearer-gas stream and comparing these values with the titrations with the Karl Fischer reagent. Finally, the accuracy of the process in determining the hydrogen content of steel has been shown by comparison with the vacuum degassing process, using samples cut from adjacent points in the centre of billets or slabs.

Some data are given from cases where the water has been absorbed and weighed, and, although this modification is satisfactory, it is not recommended since semi-micro-weighings are involved and the determination of contents in blank is much more tedious than when the Karl Fischer reagent titration is used.

Determination of oxygen and hydrogen in steel

K. Abresch (Duisbourg, Germany) also discussed the bearer-gas process.

In determining oxygen and hydrogen contents in steel vacuum equipment has been most frequently used. In recent years, when it was realized what great advances had been made in the production of very pure argon, the use of this gas as a bearer became preferable in gas analysis. By comparison with methods using vacuum, the bearer-gas processes show the following advantages:

- (1) Introduction of the steel sample into the apparatus is easier.
- (2) There is hardly any deposit of vaporized metal on the colder walls of the furnace. As is known, a deposit can lead to losses by absorption of gas.
- (3) The accuracy and reproducibility of results obtained from analysis are better.
- (4) Time for analysis is less.

In the chemical laboratory of August Thyssen-Hütte, at Duisbourg-Hamborn, the following processes, using bearer gases, have been developed:

Oxygen determination The steel sample is melted in a graphite crucible placed in a graphite tube furnace, through which a stream of argon is passing. The argon used has been previously subjected to rapid cooling by liquid air, for the purpose of removing any traces of moisture and other impurities. The nascent CO is carried along by the bearer gas and subsequently oxidized into CO₂ by a silica-iodine pentoxide gel (Schutz reagent). The carbon dioxide gas is absorbed in a solution of barium hydroxide and determined by means of a glass electrode and a pH-measuring apparatus.

Hydrogen determination This process consists of directing into a palladium spiral, using argon as the bearer gas, the mixture of gases given off from a sample of heated steel. As palladium is permeable to hydrogen in a selective way, the latter can be separated, collected by a mercury pump and measured. The palladium spiral is surrounded by a glass contained under high vacuum, which is heated in an electric furnace. The inlet and outlet tubes of the palladium spiral pass through a water-cooled silver stopper. The diffused hydrogen is drawn off by a mercury vapour pump and collected by means of a Topley electric pump. The reading is made from the difference in pressure read off on a mercury micro-burette.

Methods of oxides analysis in steels

P. Torterat, L. Backer and E. Herzog (Pompey-Meurthe-et-Moselle) dealt with the comparison of methods of oxides analysis in steels, by reducing melting in vacuum and by electrolytic separation followed by chlorination.

Among the various kinds of inclusions, oxides have a particularly important place, since their nature and their concentration are almost exclusively conditioned by production conditions. Their determination can, therefore, help in some way as a criterion of the different methods of production. The various methods of oxides analysis are, in addition to qualitative metallographic methods, a reduction in vacuum, solely quantitative, and analyses made after separation out of inclusions, which allows of both qualitative and quantitative evaluations.

Trials have been made to make the reduction method in vacuum semi-qualitative by reduction at stages in temperature, in order to compare, on the one hand, the results obtained by chemical analysis of the inclusions separated out electrolytically, and, on the other hand, to try and develop a quicker and less laborious method of evaluation. These trials have been carried out on:

- (1) Rimming steels, containing, in principle, only iron and manganese oxides.
- (2) Killed steels containing only silicon, that is oxides, silicates, and eventually silica.

(3) Killed Si-Al steels, containing also alumina.

(4) Various other special carbon steels.

For electrolytic separation of inclusions, the method and the apparatus developed by Koch and Sundermann have been used, as this allows of the work being done under very determined conditions. Electrolysis is done in the optimum active zone, studied on the density curves of current-potential. Constant potential is ensured by a potentiationstat.

The electrochemically separated residue is subjected to a Cl_2 treatment, and a fairly simple apparatus has been fixed up for this purpose. Chlorination is done at 200–250°C., in vacuum, and this is followed by sublimation. In this way carbides, sulphides and phosphides are eliminated. The temperature and time-period are in proportion to the chlorides to be eliminated. The content in metallic elements of the separated oxides is determined by means of micro-titration. In most cases colorimetric methods have been used with a Beckmann DU spectrophotometer. The elements analysed then serve to calculate the oxide content starting from the known analyses. The oxygen contents thus calculated are compared with those obtained with vacuum melting.

Reducing melting under vacuum, carried out with fractional dosings at temperature stages between 1,200–1,750°C., allows of the evaluation of the $\text{FeO} + \text{MnO}$ contents of rimming steels and $\text{FeO} - \text{MnO}$ combined in the form of silicates and of the small amount of silica alumina in killed steels. It is necessary, however, to work with molten baths containing a very low Si content in the case of killed Si or Si + Al steels, to avoid reactions between Si and FeO or MnO during the reduction operation. The reduced Si content is obtained by diluting the sample being analysed in a bath of rimming steel, previously de-oxidized with C under vacuum.

With rimming steels, the greater part of the oxides, 90% of the total, is reduced at 1,350°C. With killed steels, the proportion of oxides reduced at 1,300°C. (oxides), at 1,450°C. (silicates and aluminates) and at 1,700°C. (silica and alumina), varies according to the method of de-oxidization used.

The results obtained with these two methods agree for killed steels. As regards rimming steels, chlorination of the carbides may produce losses of FeO and MnO , and this will need to be further studied and improved.

Analysis of oxygen in metals

A 'bromidization-reduction' method of oxygen analysis was described by R. Durand and F. Nouyrigat (Paris).

Estimation of the oxygen content is one of the principal check tests of alloy steels and, particularly, of pure metals. The interest of this analysis, added

to its difficulty, has produced a large number of investigations generally based on four principles of analysis:

(a) Liberation by vacuum-reducing melting, in the form of CO .

(b) Liberation in element form by borium-fluoride attack.

(c) Separation in the form of Al_2O_3 , after aluminothermic reaction.

(d) Liberation in the form of CO by bromidization in the presence of carbon.

Study of the literature brings into evidence the lack of general application of most of these processes. Amongst them, the last method, although only slightly developed, seems to offer great possibilities.

The principle of the bromidization method was set out in 1955 and 1956 by the Americans, Codell, Norwitz and Kallmann.

After oxidization of CO into CO_2 , the latter was measured gravimetrically (fixation on ascarite), or, in the latest report, conductometrically. This method does not seem to have been widely used up to now, probably owing to the difficulties in its application. As the gravimetric method does not permit the measurement of very low contents, the conduction-measurement method was adopted at the beginning of these tests. The work done so far has made it possible to produce a variant of the process which makes it possible to differentiate in many cases between dissolved oxygen on the one hand and oxygen in the oxide form on the other. This is done by working in two stages: (1) Oxygen in solution is freed by the action of bromium on the metal, then changed into CO_2 ; and (2) the total oxygen content in the metal (dissolved and in the form of oxides, with the exception of Al_2O_3) is changed into CO by 'bromidization-reduction.'

This new technique of 'differential analysis' offers a much wider field for investigation than the standard method of vacuum reducing melting, and it shows undoubted advantages.

Each metal or alloy to be analysed requires some adaptation of the process. The following metals have been studied:

(1) Various alloy steels.

(2) Molybdenum: (a) In lumps; and (b) in powder form (particles from 1–6 microns). The method allows of differentiation being made between oxygen corresponding to oxide particles not fully reduced during making, by treating the powder with carbon alone at 1,000°C., and oxygen forming an integral part of the metallic particles.

(3) Chromium.

(4) Niobium.

(5) Vanadium.

(6) Zirconium.

(7) Aluminium.

Analysis of oxygen in metals by this process is of interest for

- (1) Wide range of application.
- (2) Results, which allow, in many cases, of distinguishing between oxygen 'in solution' and oxygen in the form of 'oxides.'
- (3) Use of a much simpler equipment than that for reduction in vacuum.

Use of gas chromatography

The method of vacuum extraction, which can be used with various variants for determining the gas content of nearly all metals, has been developed during the last few years with remarkable perfection and accuracy and was described by J. Vaclavinek and B. Bieber (Brno, Czechoslovakia). The mixture of gases in the sample under examination is released by the heating or melting of the metal in high vacuum. Melting is generally done in a graphite crucible to ensure complete decomposition of oxides and nitrides, and the mixture of gases drawn off then contains, in addition to hydrogen and nascent nitrogen, oxygen in the shape of CO and a very small amount of anhydrous CO₂. Their volume often only amounts to a few tenths of a c.c. and quantitative analysis is fairly difficult. Separation of these gases is generally done with the adjusted Orsat analyser or with the manometric analyser working under reduced pressure. In both these cases, analysis takes a long time. With the Orsat analyser, perturbations are often set up and the order of accuracy of separation is low. Manometric analysers are complex and expensive.

In analysing the mixture of gases drawn from metals with the Dosivac-Acier II apparatus, a gas Janak chromatograph has been used, which utilizes anhydrous CO₂ as bearer gas and an absorption column filled with live coal. Separation of the mixture of H, CO and N is made possible by the use of a column filled with anhydrous acid placed in the gas chromatograph behind the adsorption column containing the live coal. The anhydrous acid oxidizes, at temperatures of 120-150 C., in a selective manner, the CO into CO₂, which is absorbed at the same time as the bearer-gas in the solution of potassium hydrate with which the nitrogen-meter of the chromatograph is filled. In the nitrogenmeter it is only the volume of hydrogen and nitrogen which is measured. Their mutual separation by the adsorption column is perfect and the CO is deduced from the difference between their volumes and of the given volume of the burette of the chromatograph.

Another arrangement is possible by using cupric oxide as an oxidizer and thus allowing of a larger volume of CO₂ being determined in the said mixtures. Transfer between the gas chromatograph and the vacuum extractor apparatus can be done by

means of a small transportable gas pipette filled with mercury.

Reproduction of results of analysis of gas mixtures by the gas chromatograph is good and has been verified by the analysis of made-up mixtures of hydrogen, nitrogen and carbon monoxide on the one hand, and also by taking the gas content of a series of samples of grey iron taken from the same area of a casting. It is possible to work with a weight such that the amount of gas extracted may be 0.3 c.c. and over. The process of analysing with the gas chromatograph is handy and simple, the whole analysis taking 3-5 min. The order of accuracy of separation by the gas chromatograph is $\pm 0.6\%$.

Gas analysis can be carried out with the most suitable gas chromatograph. At the Foundry Section of the National Research and Technological Institute in Brno (Czechoslovakia) good results are being obtained in continuous analysis of gases in metals with the Dosivac-Acier II apparatus, combined with the Janak gas chromatograph.

Oxygen analysis of basic-Bessemer steel

J. Marot and I. Harveng (Charleroi, Belgium) compared various methods of oxygen analysis of molten basic-Bessemer steel. With a view to studying the state of oxidization of the bath at the end of a blow in the basic-Bessemer converter, it was necessary to find a method of taking samples and analysing them which combined both speed and reproducibility.

Various methods of sample-taking were tried, amongst which were the following: (1) A square mould with opening protected by an aluminium plate or stopped up with a wooden plug; (2) taking from killed ladle, and with contents of scoop poured on to aluminium in a mould; (3) Brower and Larsen mould; (4) Brower and Larsen bomb; (5) Speith and von Ende bomb; (6) Schenck bomb; and (7) Swinden bomb.

These various types of sampling have the general disadvantage of causing a phosphorous addition to the steel, owing to reduction by the aluminium of the slag accidentally introduced into the bomb. The metal obtained generally shows, therefore, too high an oxygen content. Analysis of bars shows considerable dispersion of oxygen. From the results obtained it appears that a Swinden-type bomb seems to be the most suitable for the conditions met with in the basic-Bessemer converter.

The samples of molten steel have been analysed by vacuum-reducing melting, by Beeghly ester-halogen method and by chemical methods. The reducing-melting method seems to be the most precise but it takes longer. This drawback can be eliminated by using reducing melting under inert gas.

Oxygen analysis of killed steels

The oxygen analysis of killed steels by reducing melting under inert gas was discussed by Miss M. Hanin (St. Germain-en-Laye, France) who said that the research work, undertaken by IRSID, on the degree of metal oxidization during working, had made it necessary to investigate a quick method of oxygen analysis of killed steels.

The original feature of this method is that analyses are carried out on 0.5-1 g. of turnings and that results are obtained as and when the samples are introduced. The sample is melted in a graphite crucible heated by high-frequency method, the crucible being changed for each analysis. The working of the apparatus is similar to that used for taking carbon measurements, with the difference that with carbon the gas is both bearer and reagent, whereas in this case the gas is simply a bearer (argon), the reducing agent being the graphite crucible.

Following the fusion apparatus, there is an analyser for measuring the CO formed. Transformation from CO into CO₂ is done by passing the gaseous stream over a catalyst with an anhydrous iodine base. Analysis of the CO₂, at present done volumetrically by using the capillary-trap method, can also be done by iodometry. It can also be conceived that use could be made of recording the variations of conductivity of a soda solution.

The method is applicable to oxygen analyses starting from sample takings with a bomb. The apparatus allows of an analysis being made in 15-20 min., all operations included.

Nitrogen analysis of cast iron and steel

In their paper, R. Boulin and J. Coulombeau (St. Germain-en-Laye) said that nitrogen analysis of cast iron and steel had been going on for a long time without it being known what it was exactly that was being analysed. The words 'soluble' and 'total' cover indeed very different realities and the results reported correspond more to trials than to real analyses.

Much research work has been done in recent years with the object of giving precision to the nature of the nitrogen analysed. Most of this work is concerned with 'total' nitrogen and the conclusions arrived at are often divergent. In order to clarify this matter a little, investigation is suggested under four headings:

(1) Methods currently used in nitrogen analysis. These methods are classified into: (a) Wet method; and (b) dry method.

(2) Development of a method of nitrogen analysis in rimming basic-Bessemer steel. This case, the simplest one, includes the three fundamental problems of every analysis by the wet method of nitrogen in ferrous metals: (a) Total transformation of the

nitrogen into ammonia; (b) isolation of the ammonia thus formed; and (c) measurement.

These problems have been respectively solved by: (a) Controlled digestion of the metal; (b) centrifugation of the hydroxides; and (c) very careful spectrophotometric measurement, obtained by a modification of the Berthelot method.

During this investigation, certain causes of errors, already suspected, have been clearly brought into evidence.

(3) Study of nitrogen analysis of basic-Bessemer cast iron and intermediate metals. In this case, two elements complicated the problem, carbon and silicon. The possible existence of combinations of these elements with nitrogen raises the problem of attack. A sulphuric method, with white fumes, has been used.

In order to test the validity of the results obtained, comparative analyses have been made with a method derived from that of Dumas for the analysis of organic nitrogen. Agreement between the two techniques is satisfactory.

(4) Study of nitrogen analysis in alloy steels. In this field there is an immense amount of work to be done. There is still insufficient information on the chemical behaviour, and even on the nature, of the many nitrides concerned.

However, it is thought that simultaneous use of the various methods of analysis mentioned above and the combination of the many efforts now being made will allow of the convictions recently acquired being substantiated and of the field of knowledge in this matter being extended in the near future.

Nitrogen in the basic arc-furnace

A contribution to the study of the evolution of nitrogen in the basic arc-furnace was made by R. Ferry and R. Lescuyer (Le Creusot).

As long ago as 1932, H. W. Graham put forward nitrogen as perhaps the most important element owing to the 'sensitiveness' which it caused in steel (ageing, hardenability . . .). At present, the relationship between the various states of nitrogen and the properties of steel is the subject of numerous investigations. New problems in manufacture will inevitably flow from these and already it is necessary to possess a good knowledge of the evolution of nitrogen in molten steel during the course of its working.

The present work can be considered as a contribution and addition to what is already known in this field through the work of Takadera in particular. The main object is to provide practical and usable data for the arc-furnace steelmaker. Some items are also added to help in the comparisons frequently made, from the point of view of the nitrogen content, between open-hearth and electric steels.

In accordance with the use to which a steel is to

be put, nitrogen becomes either a problem of incorporation or, more frequently, of elimination, and it is from this point of view that this investigation must be regarded. Observations were made during the making of a hard steel, with 0.7% C and a nitrogen content (N_2) limited to 100 p.p.m., made in a 15 35-ton basic arc-furnace. Making was by usual electric melting; solid charge, double slagging, reduction of carbon towards 0.15-0.20%, and recarburization with graphite powder, with varying methods of deoxidization. Owing to its nature and to quantity involved, amounting to more than 1,000 casts, an excellent opportunity was provided for studying the evolution of nitrogen.

Oxidizing phase of charge melting The material charged was uniformly basic-Bessemer scrap analysing 150-200 p.p.m. nitrogen. Denitriding during melting was expensive, the molten metal containing 90 p.p.m. N_2 . From the start there is a relationship between the N_2 content when cast and that at melting. It is an advantage, therefore, to have as low an N_2 content as possible when melting, and this means that it is advisable to introduce a protective slag from the beginning of charging and to use limestone instead of lime. If possible, scrap with a low N_2 content should be used.

Oxidizing refining period There is a definite denitriding action during refining with oxygen, this being quite large, being from 90 p.p.m. on melting to 60 p.p.m. on average. This operation tends to level out the fairly large differences sometimes obtained for the N_2 contents during melting. On the other hand, large variations in the refining process, speed and volume of decarburization, are not reflected by any notable changes in the drop in nitrogen. In current practice, decarburization of 0.4% of C in about 1 h. is sufficient.

Reducing period between refining and tapping During this operation, when the main operation is the delicate one of recarburizing with powdered graphite on the bare bath, the change in nitrogen is fairly small, consisting of a rise of 10 p.p.m. (N_2 before tapping: 70 p.p.m. average). This pick-up is presumably akin to the much stronger one which is observed during teeming into ladle.

Teeming into ladle and casting During this operation there is intense working between metal and slag. A systematic pick-up of nitrogen (N_2) is registered, this varying greatly from 0-90 p.p.m., sometimes accompanied by a small carbon pick-up. The hypothesis of nitrogen being taken from the surrounding air has been rejected as a result of experiments. The present tests have shown a definite relation between this nitrogen pick-up and the N_2 content of the slag, the latter being itself tied up with the presence of carbon in this slag. The formation under the arcs of a compound of C- N_2 -Ca is quite feasible. This explanation agrees with that

of Takadera and completes the older one of Schwarz. This passage of nitrogen from slag to metal is slight in the furnace but it can be activated by magnetic stirring. It obviously becomes larger during teeming into the ladle.

Given the determining action of the presence of C in the slag, it has been possible to establish a general relationship between the N_2 content of the steel and the percentage of powdered graphite, a relationship which holds good for basic arc-furnaces.

As a general rule, the N_2 content of the metal in the ingot mould is identical, within a very small margin, with that of the metal in the ladle and does not vary between the beginning and the end of pouring. However, if a number of well-defined conditions are present, the nitrogen and carbon contents can increase simultaneously and very rapidly, particularly in the last ingots coming from metal which has been most in contact with the ladle slag. This interesting phenomenon, accidentally noticed, has been reproduced experimentally and studied. But the mechanism of the diffusion which takes place in the ladle has still not been properly explained, although it does seem to bear some relation to the pick-up of nitrogen during tapping into the ladle.

The attempt to eliminate or limit nitrogen is not an easy one, but the following steps may help: (a) Use of low N_2 scrap; (b) formation of limestone slag from beginning of charging; (c) fairly heavy refining, but not overdone; (d) if possible, stop refining at a C constant near that required when casting: or, if not, limit recarburization with graphite powder and see that a good yield is obtained; (e) as a general rule cut out the carburized slag; (f) avoid a too strong method of deoxidizing in the furnace; and (g) deoxidization in ladle would be preferable.

For any particular production to be realized, these measures are sometimes not all applicable together and a compromise has to be made.

Sheffield made

A SHORT COLOUR FILM, purporting to show how Sheffield is meeting the demand for special steels for modern requirements, has just been released by the British Iron and Steel Federation. To tackle such a subject in the short space of 15 minutes' viewing time is no easy task, and the succession of unrelated sequences which make up this film do not provide a satisfactory solution. Some beautiful shots of a rocket being fired, the interior of an atomic power station, and other modern marvels made good viewing, but are hardly as informative of Sheffield's steelmaking as the few minutes in which we are allowed to see some splendid pictures of special steels being made with modern equipment. If short films of this kind are to have genuine informative value, every minute of running time should be looked upon as precious, so perhaps the gimmicks and whimsicalities could be dispensed with; certainly the inevitable concluding sunset seems an unduly protracted ending to such a short day.

National Association of Drop Forgers and Stampers

the annual banquet, 1959 and tenth technical convention

THE ANNUAL BANQUET of the NADFS took place on November 5 this year and once again filled to capacity the Grosvenor Rooms of the Grand Hotel, Birmingham. Many members of the heavy engineering industry, the motor car industry, and steel-makers, are able to enjoy this opportunity of meeting together each year, and it is a pity that practical considerations imposed by the space available limits a further increase in numbers.

The toast of the Association was proposed by The Viscount Knollys, G.C.M.G., M.B.E., D.F.C., chairman, Vickers Ltd., and replied to by the president of the Association, Mr. J. H. Swain. It was during the course of his speech, that the president made the announcement, reported in last month's

METAL TREATMENT, that the NADFS was to sponsor the formation of a research organization for the drop forging industry.

Mr. G. W. Richards, director, High Duty Alloys Ltd., proposed the toast of the 'Guests,' which was responded to by Mr. C. M. Vignoles, C.B.E., managing director, Shell-Mex & B.P. Ltd., and by Mr. S. F. Burman, C.B.E., pro-chancellor, The University of Birmingham. The proceedings concluded with a short speech by Mr. W. E. A. Redfearn, managing director, English Steel Forge and Engineering Co. Ltd., who, in proposing a toast to the 'President' thanked Mr. Swain for presiding at the banquet and paid tribute to his work as president.

BELOW (left to right) Seen at the drop forging annual banquet are Mr. L. C. Heaven, Mr. R. W. N. Danielsen, M.B.E., T.D., The Prime Warden The Worshipful Company of Blacksmiths, Comdr. K. Gordon Couch, and Mr. Keppel F. Massey



ANNUAL BANQUET 1959

(names read left to right)



*Mr. S. Johnson, president elect,
Mr. J. H. Swain, president,
and Mr. A. L. Stuart Todd,
C.B.E., director of the NADFS*

*Mr. W. E. A. Redfearn,
The Viscount Knollys,
G.C.M.G., M.B.E., D.F.C.,
Mr. C. M. Vignoles, C.B.E.,
and Mr. J. H. Swain*



*Mr. H. F. Asbridge,
Mr. C. W. Perry,
Mr. D. W. Turner, J.P.
Mr. G. Tipler, and
Mr. I. F. Insch*

Tenth technical convention

The tenth technical convention of the NADFS was held at Droitwich on November 20 and 21 this year under the chairmanship of Mr. W. E. Golcher, chairman of the Technical Committee.

Three papers were presented by their authors and all provoked considerable discussion. The first paper, *Development of forgings for the jet engine*, by Mr. W. J. M. Moore, Rolls-Royce Ltd., discussed the particular requirements of forging the more complex parts of a turbine engine. Mr. Moore related these requirements to engine performance, methods of inspection, etc., and made a strong plea for closer collaboration between the forger and the user so that the reasons for the demands on the producer of forgings could be understood. He also described an interesting technique to study the effect of flow on centre segregation in a billet.

Studies of the cold deformation of materials by Mr. H. L. D. Pugh, National Engineering Laboratory, described certain aspects of research at the National Engineering Laboratory on cold forging and extrusion of metals.

Because of the impracticability of carrying out full-scale forging operations in the laboratory, small-scale model tests had been used. The tests were concerned with the drop forging of materials between parallel platens and the validity of the model tests and the conditions under which the model tests had to be carried out to predict valid full-scale results had been established. A study had been made of the effects of specimen geometry, repeated impact and strain rate on the unrestricted flow of lead, aluminium and copper between lubricated and unlubricated parallel platens.

In the study of the cold extrusion of non-ferrous and ferrous metals, it had been found that the increase in temperature of the metal due to the work of deformation and die geometry markedly influenced metal behaviour during extrusion. Some aspects of this work were briefly discussed by the author, in particular the effect of reduction and ram speed on the extrusion pressure and on the increase in temperature.

Data had been obtained on the behaviour of an extensive range of carbon and alloy steels under different conditions of extrusion. The study indicated that the process was limited by the high working stresses in the tools rather than by the ductility of the material. The effect of the chemical composition of the steel could be deduced in general terms and the results indicated that the low-carbon steels showed greater proportional increases in hardness for a given reduction than did higher carbon or alloy steels.

Since a superimposed fluid pressure makes pos-

sible the deformation of a metal to a much greater degree than is normally possible at atmospheric pressure, it was thought that an improvement could be expected by the 'pressurized' extrusion of difficult materials. Preliminary results were given for extrusions carried out under a superimposed fluid pressure of the metals bismuth and magnesium, which could not be satisfactorily extruded under normal atmospheric conditions.

Forging in the earth-moving industry by Mr. A. J. Balfour, Caterpillar Tractor Co. Ltd., stressed the reasons why the author found it necessary in his industry to make particular demands. Mr. Balfour illustrated his talk with slides and film.

The specialist discussion groups which were introduced for the first time in last year's convention were held again this year. There were two of these: one for metallurgists in which Mr. Pugh led a more detailed discussion on plasticity; and another for die-shop supervisors to discuss with Mr. Swain, of Wickmans Ltd., aspects of spark machining. This served as an admirable follow-up of the recent symposium on the subject.

Extrusion of aluminium and its alloys

The lowest temperature at which a product can be extruded may be determined solely by the available press capacity. On the other hand, if the temperature is too high, undesirable metallurgical changes may occur. This upper temperature limit depends on both the temperature of the billet and on the heating-up of the product caused by conversion of the work of deformation into heat.

Specimens of 99.5% pure aluminium and a high-strength aluminium alloy (D.T.D. 363) have been extruded in a hydraulic press at billet temperatures ranging from 20-450°C. The effect of ram speed and extrusion ratio (the ratio of the cross-sectional area of the billet to that of the product) on the extrusion pressure and temperature rise in the product has been studied.

The temperature rise resulting from the work of deformation can be quite large. For example, at an extrusion ratio of 200 and a billet temperature of 300°C. there is a temperature rise with aluminium of 170°C. at a ram speed of 30 in. min. For comparable extrusion conditions the temperature rise in the alloy is greater than in the pure metal. Hot shortness (cracking of the surface of the product) occurred in the alloy under various combinations of billet temperature, extrusion ratio and ram speed. This failure took place when the temperature of the product reached about 480°C. If this alloy is extruded at the usual billet temperature of 400°C., ram speeds must be kept low to prevent the onset of hot shortness.

For extrusion ratios greater than 4 it was found that there is a linear relation between the extrusion pressure and the logarithm of the extrusion ratio. There is also a linear relation between extrusion pressure and billet temperature. Preliminary investigations of the effects of extrusion conditions on the hardness, tensile strength and dimensional accuracy of the product have also been made.

Further information is given in *M.E.R.L. Plasticity Report No. 146 (Extrusion of metals. Part 7—Pure aluminium and aluminium alloy, D.T.D. 363, by K. Ashcroft and G. S. Lawson)*, available from the Mechanical Engineering Research Laboratory, East Kilbride, Glasgow.

Application of electron microscopy

Phase formation in the structure of brittle transformer sheet

JAROSLAV JEZEK, JOSEF VOBORIL and VLADIMIR CIHAL

A theoretical and experimental study of the mechanism of brittle phases in the structure of transformer sheet has been made with the aid of the electron microscope, and some practical conclusions reached. The work was reported in Hutnické Listy, 1959, (9), and the English version given below is the ninth of a series illustrating the role of the electron microscope in metallurgy. The first two authors are at the State Research Institute for Materials and Technology, and the third is at the State Research Institute for Protection of Materials, Prague

BRITTLINESS OF TRANSFORMER SHEET, which renders it impossible to shape during its fabrication, is always the cause of a large quantity of unusable scrap and of considerable losses of materials and working time. This phenomenon has therefore been the subject of many works which have shown that brittleness in the structure of the sheet is accompanied by the existence of a foreign phase precipitated on the boundaries of the ferritic grains. Research to determine what added elements and what treatments promote or inhibit the formation of this phase has been reported, and it has been established that its formation is promoted by an increase in the content of silicon and carbon. On the basis of this finding the opinion has been expressed that the phase consists of a mixture of cementite, of silicon carbide and of a eutectoid which has not been more accurately defined,¹ but it proved impossible to establish the exact nature of this phase.

In his earlier works the first of the authors of the present paper^{2, 3} studied the mechanism of the precipitation and diffusion of the brittle phase already indicated along the grain boundaries, and drew attention to the fact that these processes are accompanied by the formation of a variety of different phases on the boundaries of the ferritic grains as intermediate stages in these processes. This state of the grain boundaries is especially harmful both from the point of view of brittleness, as well as from the aspect of core wattage losses. At

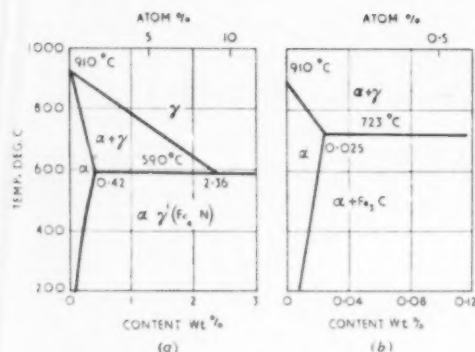
the same time the author showed that brittleness may be avoided by diffusion of the brittle phase into the matrix by heating the sheet at 800–900°C. with subsequent rapid cooling at a rate of 200°C./h. at least down to the temperature range of 200–300°C., and that on the other hand brittleness of the sheet may again be brought about through the formation of a brittle phase as a result of long-term heating at temperatures above 400°C.

On the basis of these conclusions we decided on a more detailed study of the conditions and the mechanism of the formation of the brittle phases in the structure of transformer sheets. The aim of our work was to determine how this phase is formed, and what elements participate in its formation.

Theory

As the material for the experiments we chose sheet 0.5 mm. thick with very marked brittleness, which was distinguished from other melts by its higher content of carbon, silicon and nitrogen (4.34% Si, 0.02% C, 0.01% N). The sheet fractured even as a result of very slight bending without any plastic deformation whatever. As a result of solution heat treatment (1,100°C., 2 h., *in vacuo*) the brittleness was eliminated, and it was possible to bend the sheet without fracture.

If we work on the basis of the established fact that it is possible to diffuse the brittle phase into the matrix, and on the other hand again cause brittleness by heating to a relatively low temperature, it is

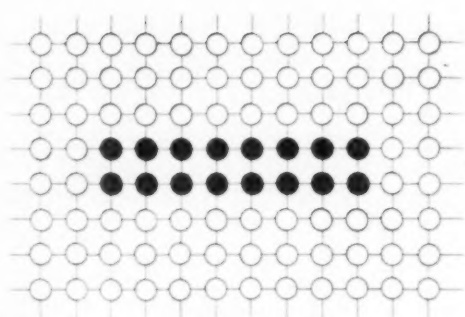


1 Solubility of carbon and nitrogen in alpha iron: (a) Fe-N, (b) Fe-C

probable that the first stage of the precipitation of this phase (or phases) will take place in a similar manner to the precipitation of disperse phases from the saturated solid solutions during hardening. From the curves of the solubility of carbon and nitrogen in alpha iron, fig. 1, it is evident that the alpha solid solution is susceptible to dispersion hardening, and that this is mainly due to the influence of nitrogen, the maximum solubility of which in the solid solution is almost ten times greater than the solubility of carbon. We can therefore expect that the precipitation of the secondary phases during heating will be governed by the laws which are generally valid for the precipitation of hardening phases.

The explanation of the structural changes which take place during dispersion hardening has undergone distinct evolution, and at the present time it is based on the so-called theory of coherent phases.¹⁰⁻¹² This theory divides up the phenomena connected with hardening into two groups. The first group is made up of the processes which precede precipitation and do not in themselves give rise to structural changes; they consist of the piling up of the atoms of the component in solution at definite points on the lattice of the matrix. The second group is made up of the actual precipitation, which is apparent in the occurrence of visible formations of the hardening phases.

This theory was supported by the experimental results of Preston¹³ and Guinier,¹⁴ on the basis of X-ray analyses of the structures they described the processes taking place in the early stage of hardening, and came to the conclusion that at the start of hardening breakdown of the supersaturated solid solution does not occur, and that independent structures of the hardening phase are therefore not precipitated. In the stage of the hardening process which precedes precipitation the dominant part is



2 Diagram of Guinier-Preston zone

played by the fluctuation in the concentration which creates conditions whereby the solid solution is not always saturated by the constituent in solution at all points. Alongside the zone of the basic lattice with the average concentration of this constituent there exist zones with a higher or lower content of alloying elements.

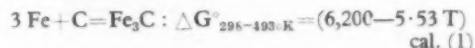
The zones with varying concentrations are formed preferentially at distinct points on the lattice, for instance on the grain boundaries, on the boundaries of the mosaic block structures, and especially in suitable crystallographic planes. In the cubic system these planes are (100), (101) and (111). These zones of piling up of the foreign atoms in the lattice of the solid solution (fig. 2) have been called the Guinier-Preston zones. Their transverse dimensions amount to only a few layers of atoms, whereas their longitudinal dimension is dependent on the temperature at which they are formed, and varies within the limits of tens to hundreds of Ångströms. Under favourable conditions during further heating these zones become stable seed crystals of a transitional disperse phase, which is transformed during the later stage into a stable phase.

The maximum hardness of the hardened matrix corresponds to the extent of the existence of the Guinier-Preston zones which are coherent with the basic lattice prior to precipitation; these zones promote formation of internal stresses of the third order, obstruct the extension of the slip bands and so likewise extend the degree of increase in hardness. Diffusion of the visible precipitates is accompanied by a renewed fall in the hardness of the matrix. The conditions for the formation of the hardening phase from the Guinier-Preston zones affect the morphology of the particles formed, which precipitate in the form of acicular crystals deposited in the already-mentioned crystallographic planes.

On the basis of these hypotheses, in the present instance where we have a solid solution of alpha iron containing silicon and saturated with carbon and

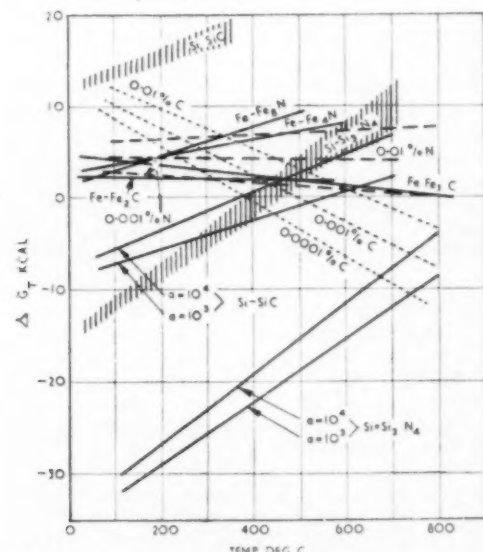
nitrogen, we expected the formation of acicular precipitates in the crystallographic planes of the ferrite, and this theory was confirmed by the results of our research. But at the same time it was shown that the whole action of the precipitation of the brittle phase in transformer sheet is in some respects more complex. Evidence of this was also provided by thermochemical analysis of the stability of the carbides and nitrides, which we carried out on the basis of thermo-dynamic data both from older, and also from the most recent, literature sources.

Carbon can react in the alpha solid solution with iron and silicon to form carbides, i.e. cementite, ϵ -iron carbide and silicon carbide. The free enthalpy of the formation of cementite, according to the statements of Kubaschewski and Evans,¹⁵ for the reaction



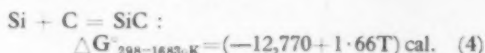
$$\Delta G^\circ_{400-1115\text{K}} = (6,380 - 5.92T) \text{ cal. (2)}$$

Information on the thermodynamics of the formation of the carbide of ϵ -iron is not available in literature sources. Only Browning, De Witt and Emmett¹⁶ report for the reaction

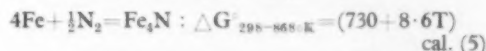


3 Changes in the thermochemical potential of carbon and nitrogen, and of carbides and nitrides of iron and silicon in relation to temperature for the various concentrations and activities shown

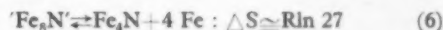
For assessment of the thermodynamic stability of silicon carbide we used the statement of Richardson¹⁷ for the reaction



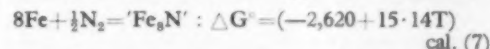
Nitrogen in the solid solution can react with iron and silicon to form nitrides. The solubility of nitrogen in alpha iron (or in the solid solution of iron with silicon) in equilibrium with nitride of iron and silicon has been studied and written up by many authors, but in many instances with considerably differing results.¹⁸⁻²⁸ The solubility of nitrogen with the nitride Fe_4N has been more thoroughly studied by Dijkstra,²⁰ whose results were also confirmed by Fast and Verrijp,²⁴ Corney and Turkdogan,²⁵ and Rawlings and Tambini.²⁶ On the basis of an assessment of the results obtained by the authors mentioned, for the temperature relationship of the standard free enthalpy of nitride of iron it is possible to write this equation for the reaction



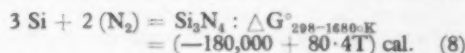
On the other hand as long ago as 1949 Dijkstra²⁰ discovered that the solubility of nitrogen at low temperatures is greater than that corresponding to the equilibrium with the nitride Fe_4N , and it was apparent that at these temperatures nitrogen dissolved in alpha iron is in equilibrium with the untechometric nitride ' Fe_8N ' ($=\text{Fe}_8\text{N}_2$). On the basis of the values of Fast and Verrijp,²⁴ later authenticated by Rawlings and Tambini also,²⁶ for the dissolution heat of the nitride ' Fe_8N ' and of nitrogen in alpha iron (9900 and 7280 calories respectively) and for the change in entropy of the reaction



we calculated the equations of the temperature reaction of the free enthalpy for the reaction



In order to assess the thermochemical stability of the nitride of silicon we used tabulated values¹⁸ compared with the heat of dissolution of silicon of nitride according to Rawlings²⁹ for the reaction



On the basis of equations (1)-(8) we compared the stability of carbides and nitrides of iron and silicon in a diagram of the temperature relationships of the free enthalpies of carbides and nitrides for every gram atom of carbon and nitrogen (the solid lines in fig. 3). The lines for the carbide and nitride

of silicon correspond to activity coefficients of silicon of 10^{-3} and 10^{-4} on the basis of the statement of Rawlings,²⁹ who deduces an activity coefficient at 1,000°C. $a_{\text{Si}} = 8 \times 10^{-3}$ for a concentration of 1.9% Si in iron from the equilibrium state between silicon, nitrogen and silicon nitride. If we apply this data to transformer steel, in the given instance containing 4.34% Si, the activity coefficient of the silicon in the ferrite is around 10^{-4} . In order to calculate the thermodynamic properties of carbon dissolved in ferrite, it is necessary to find first the activity coefficient for various concentrations.

The activity coefficients of the alloying elements, such as Si, Al, Ti, B and others, which react exothermically with iron (in the present instance, e.g. for FeSi $\Delta H_{298} = -19.2 \pm 1.5$ kcal./mole³⁰), have low values as a result of the low concentration. Apart from this silicon, as Smith³⁷ maintains, at a content of over 1%, increases the activity coefficient of carbon dissolved in gamma iron, and according to Small and Wilson²³ in liquid iron also. Where there is considerable difference between the concentrations of carbon and silicon, we must not assume that carbon brings about changes in the activity coefficient of an alloying element.

On the basis of the analysis which has been carried out and summarized in the diagram in fig. 3, and in the light of the conclusions of the authors already mentioned, we consider that the equilibrium line which corresponds to the concentration of silicon in the transformer steel under investigation lies above the line for $a_{\text{Si}} = 10^{-3}$ both in the Si-Si₃N₄ system, and also in the Si-SiC system. At a first glance it might be expected that Si would act as a strong carbide-former in the steel, and namely at temperatures at which the lines for the Si-SiC system fall below the cementite line. Silicon, however, as has already been mentioned, belongs to the elements which react strongly with iron, and the partial heat of dissolution for the dilute solid solution of silicon in iron is approximately 20 kcal./gram atom.¹⁷ From this it follows that the lines in the Si-SiC and Si-Si₃N₄ systems must lie above the lines for the appropriate activity of silicon, and this is roughly about 20 kcal. The level of these lines for the activity of Si between 10^{-3} and 10^{-4} is indicated in fig. 3 by the shaded bands and quite plainly eliminates the existence of silicon carbide in the transformer steel.

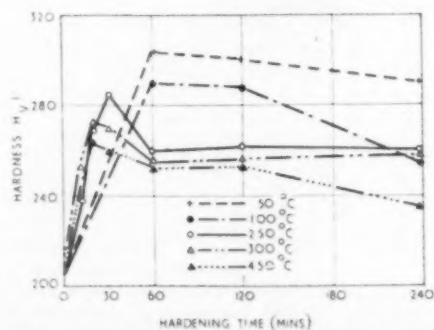
From the thermochemical analysis which has been carried out it follows that the most stable phase in transformer steel apart from ferrite is silicon nitride. At low temperatures, however, this stable nitride cannot precipitate from a supersaturated solid solution as a result of the low diffusion velocity of silicon. According to the diagram in fig. 3, it is therefore probable that below a temperature of

220°C., first of all there is precipitation of the unstoichiometric nitride Fe₁₆N₂₃, in which half of the sites for nitrogen atoms in the lattice are vacant. The locations of the iron atoms in the lattice of this nitride are similar to their locations in alpha iron,²⁴ so that for the formation of nuclei of this phase much less activation energy is required than for the formation of the nitride Fe₃N, in which the iron atoms are ordered as in gamma iron. Evidence of the preferential precipitation of the nitride Fe₁₆N₂₃ is therefore provided not only by the higher chemical metastability below a temperature of 220°C., but also by its greater crystallographic symmetry with respect to the basic alpha solid solution by comparison with the nitride Fe₃N. Above a temperature of 220°C. the stability of the nitride Fe₁₆N₂₃ is extremely low, and the thermal fluctuations of the atoms in the alpha iron lattice are already so great that direct formation of the nitride Fe₃N is made possible without the transitional precipitation of Fe₁₆N₂₃.

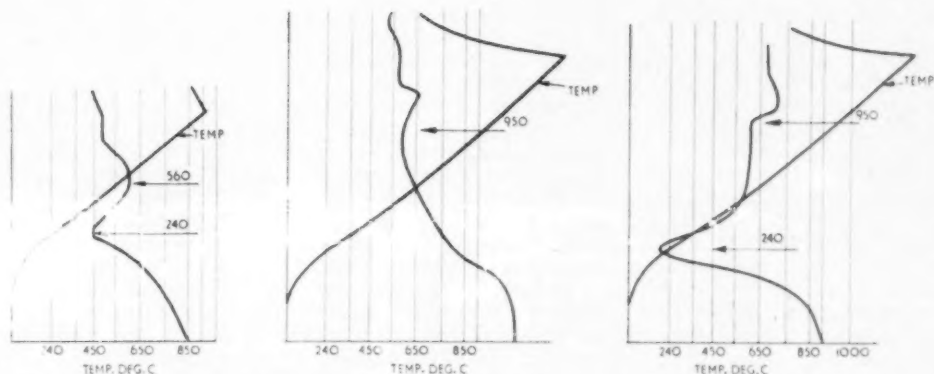
In view of the fact that both the lines of the temperature relationships of the function ΔG_T of the nitrides Fe₁₆N₂₃ and Fe₃N pass from a metastable zone into a zone of instability, it is evident that with increasing temperature during the breakdown of the super-saturated alpha solid solution, alloyed with silicon, increasingly greater quantities of silicon nitride will be formed, while nitrides of iron will gradually disappear from the structure. This conclusion was completely confirmed by the results of our experiments.

Experimental details

For investigating the sequence of the precipitation of the secondary phases from the alpha solid solution and of the further structural transformations at high temperatures we used thermal analyses and measurements of the hardness of the matrix. In fig. 4 is shown the hardness sequence of the matrix, which after solution heat treatment



4 Hardness sequence of the ferritic matrix during hardening



5 Thermograms of the experimental material: (a) after solution heat treatment, (b) in the initial state, (c) in the initial state, but after heating to 1,000°C. and cooling at 5°C./min. in the furnace

(1,100°C., 2 h., *in vacuo*) was subjected to heating in air at 50, 100, 250, 300 and 450°C. for periods of 10, 20, 30, 60, 120 and 240 min. From the hardness sequence it is evident that under these conditions hardening of the matrix takes place, and that from this matrix therefore a secondary phase is precipitated, which in the early stage of its formation brings about an increase in hardness. The shape of the hardness curves and their sequence in relation to temperature and time is in conformity with the curves which were obtained by Davenport and Bain³³ for the hardening of iron with 0.06% C.

The thermal analysis was carried out by the method, and with the equipment, described by Tuma and Vyklicky.³⁴ In fig. 5 (a) is given the thermogram obtained for the material which was subjected after solution heat treatment to thermal analysis at a heating rate of 8°C./min. It shows that in the temperature range from 240 to 560°C. in this material there occur structural transformations, which manifest themselves through the consumption of thermal energy. A further similar change takes place at a temperature of over 900°C. Both these structural changes exist only in material which has been subjected to solution heat treatment.

Materials in the initial brittle state (fig. 5 (b)) did not display any change whatever in the first temperature range, while in the upper range (above 900°C.) only an endothermic reaction was produced. It is evident that the arrest on the thermal curve in the range above 900°C. is dependent on the breakdown of the initial brittle phase present on the boundaries of the ferritic grains, whereas the arrest in the temperature range from 240 to 560°C. relates to hardening phases, for it exists only in material which has been subjected to solution heat treatment, and is therefore susceptible to hardening. This was in fact confirmed by a subsequent experiment in

which a thermal analysis was carried out on some of the initial material which, after the first cycle (fig. 5 (b)), was cooled at a rate of 5°C./min. and once again analysed. In this second cycle both the arrests appeared on the thermal curve, not only above 900°C., but also in the temperature range from 240 to 560°C. (fig. 5 (c)).

In order to explain the nature of the structural changes which had thus been established individual specimens were subjected to metallographic and structural analysis after precipitation heat treatment. Figs. 6 and 7 show the structure of the specimens investigated, as it was revealed in the optical microscope at a magnification of $\times 330$, whereas in figs. 8, 9 and 10 are shown prints of extraction replicas produced under an electron microscope at a magnification of $\times 5,000$.

As the material for the extraction replicas collodion or graphite was used. The replicas were shadowed with chrome, and this was done from the same side as the precipitate in instances where it was a question of studying the formation and deposition of finely dispersed particles (fig. 9). In the instance where the particles were densely piled up together (fig. 10), the replicas were shadowed on the reverse side, in order that the shadows thrown by the particles should not confuse the image, while preserving the favourable effect of shadowing in emphasizing the relief of the structure of the matrix.

In fig. 6 (a) is shown the structure of the material in the initial state, which is accompanied by the existence of a brittle phase precipitated in characteristic formations along the boundaries of the ferritic grains, such as are, in fact, familiar to us from previous works. After solution heat treatment this phase disappears, and the structure of the material is shown to be homogeneous, being com-

posed only of ferritic grains with clean boundaries (fig. 6 (b)).

The corresponding photographs from the electron microscope show that the grain boundaries and the matrix are devoid of visible precipitates after the solution heat treatment, and this applies after deep etching, the depth of which is shown by the occurrence of etching in the ferritic grains (fig. 8).

On the grain boundaries there exist homogeneous or heterogeneous strips which preclude contact between two grains with varying orientations. Fig. 8 (c) shows an instance where a homogeneous transition strip about 5μ wide exists between two grains. In contrast to this in fig. 8 (d) is reproduced an instance where the transition zone consists of four strips with varying orientations, which form a series of abrupt changes from the orientation of one grain to that of another.

We consider this structure of the boundaries of the ferritic grains to be one of the causes of the diverse nature of the boundaries of these grains, for it is evident that the boundaries of the individual strips with varying orientations represent the areas of increased piling up of the lattice deformations. The diffusion of foreign atoms from the interior of the ferritic grains or from the foreign phase which has now been dissolved, therefore penetrates into these areas, and this brings about a change in the chemical composition and causes the different etchability of these areas. After etching this is manifested in the system of narrow strips running parallel to the original interface between two grains.⁸ Figs. 8 (e) and (f) show the boundaries of two grains with such orientations; in these instances the junction is not always necessarily separated by a pronounced transition strip.

In figs. 6 (c) and (d) is shown the structure of specimens after precipitation heat treatment at a temperature of 250° C. for periods of 20 and 30 min. respectively. They show that a fine precipitate is liberated from the matrix; as the duration of the heat treatment is increased, this precipitate becomes coarser and builds up the characteristic formations which manifest themselves in the cross-section as acicular crystals. The corresponding photographs of the extraction replicas, figs. 9 (a) and (b), show that here we have platelet structures, whose diameter in the initial stage is less than 1μ , and whose thickness is so small that they can be permeated by the electron beams; in consequence on the electron photograph they do not stand out in very great contrast (fig. 9 (b)). During the longer period of heating (250° C. for 30 min.) these platelets grow to a diameter of 1 to 2μ and attain a thickness of 0.1μ (figs. 9 (c) and (d)).

From the electron micrographs it is evident that the platelets are orientated in such a way that their basic planes run parallel with three crystallographic

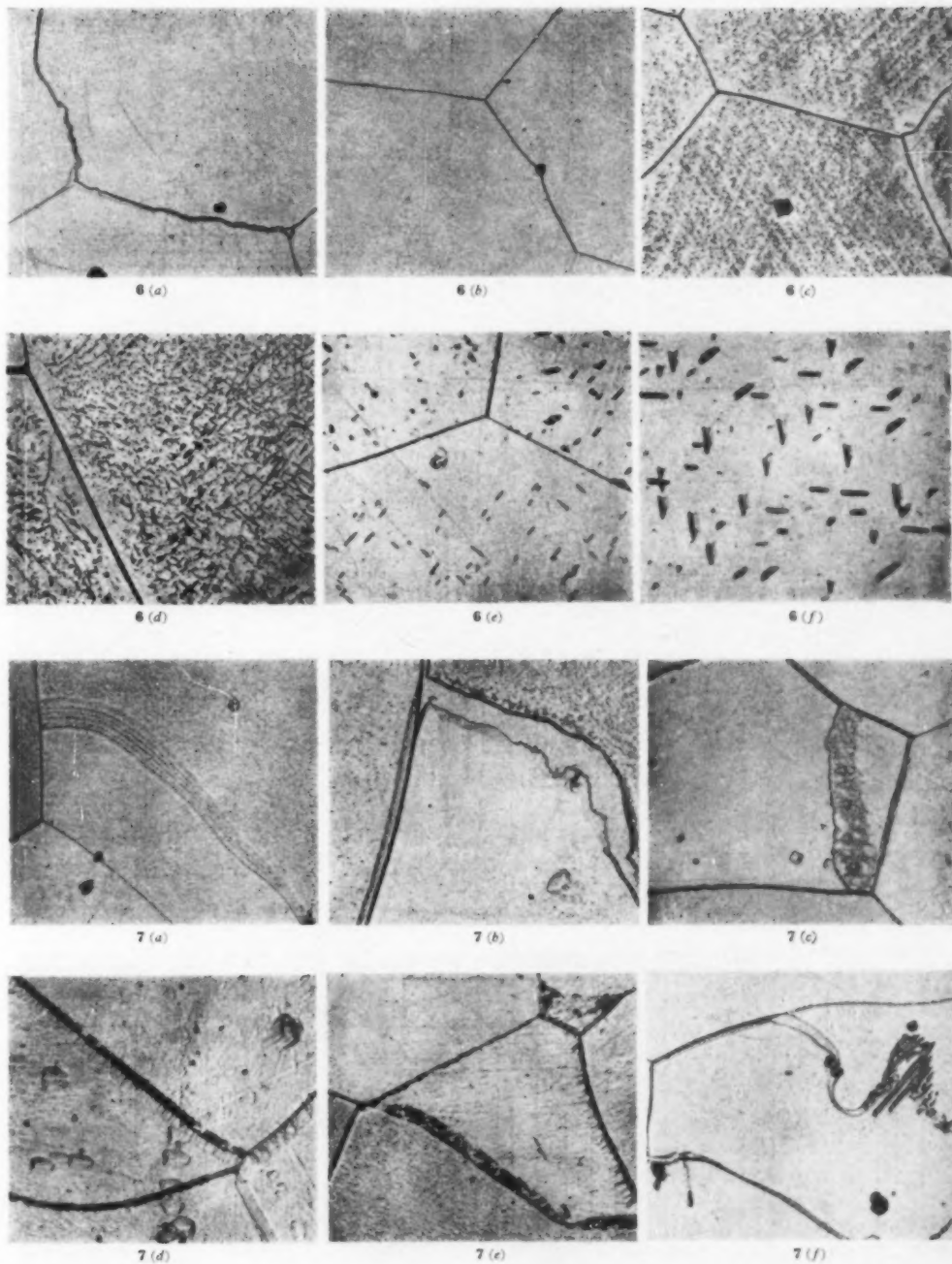
planes of the lattice of ferrite which are at right angles to each other. In this stage the precipitate was suitable for electronographic structural analysis with the use of a collodion extraction replica. The relevant diffraction diagram is shown in fig. 9 (e). Its assessment showed that here we have the transitional nitride of iron, Fe_{16}N_3 . This morphological and structural finding agrees with the results of the work of Booker, Norbury and Sutton,³³ who found this phase in nitrided steel.

On increasing the temperature of the heat treatment to over 250° C. the fine platelets of Fe_{16}N_3 disappear, and in the structure there remain only coarse lamellae, attaining a length of over 10μ , which are not suitable for electronographic structural analysis as a result of their dimensions (figs. 6 (e) and (f) and 9 (f)). From the morphological similarity with the formations presented in the work of Booker and his collaborators, and on the basis of our own thermochemical analysis we judge this to be the nitride Fe_3N .

Simultaneously another precipitate starts to make its appearance on some of the boundaries of the ferrite. X-ray structural analysis of the precipitate formed in this range of temperatures indicated the presence of nitride of iron and nitride of silicon. As a consequence of the unsuitable size of the particles, however, the X-ray lines were difficult to measure and the analysis was unreliable.

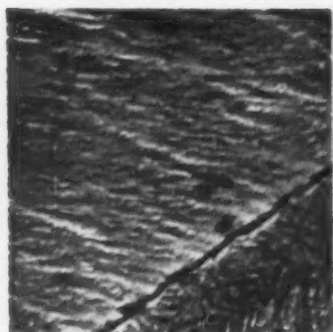
Figs. 7 (a) to 7 (c) show that in the range of temperatures from 250 to 450° C. there is repeated diffusion of the original precipitate into the matrix and the formation of an area with a varying degree of etchability along the boundaries and within the individual strips running obliquely to the grains. By measurement of the micro-hardness we established that the hardness of these areas gradually increases, and we therefore judge this to be the piling up of atoms of foreign elements, which is the preliminary form of precipitation of new phases. The start of this new precipitation is connected with the formation of heterogeneous strips along the boundaries of, and within, some of the grains (figs. 7 (a) and (b)) and is manifested by the formation of fine particles in these zones (figs. 10 (a) and (b)).

After heating at a temperature of 450° C. for four hours, in the structure is liberated a completely visible precipitate (figs. 7 (d) and (e)) oriented along the original boundaries of the ferritic grains and along the boundaries of the new substructures which are formed at some points from the strips running at an oblique angle to the grains (fig. 7 (c)) which have already been mentioned above. Figs. 7 (d) and (e) show that these precipitates are as a rule located on one side of the boundary and oriented in the direction of one of the two neighbouring grains. This special way in which the

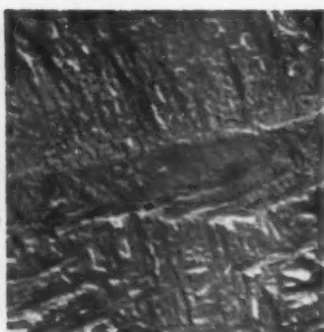


6 Structure of transformer sheet after various heat treatments: (a) initial state, (b) 1,100°C., 2 h., in vacuo, (c) 1,100°C., 2 h., in vacuo, + 250°C., 20 min., (d) as (c), 30 min., (e) + 300°C., 20 min., (f) as (e), 30 min. $\times 330$

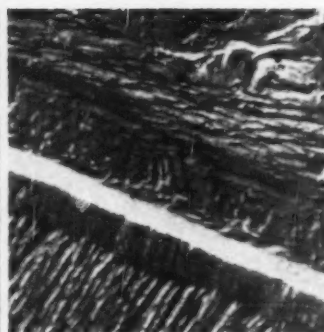
7 Structure of transformer sheet after various heat treatments: (a) 300°C., 1 h., (b) 300°C., 2 h., (c) 450°C., 1 h., (d), (e) 450°C., 4 h., (f) 700°C., 1 h. $\times 330$



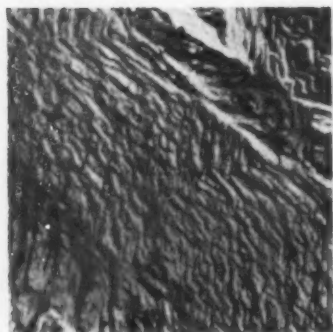
8 (a)



8 (b)



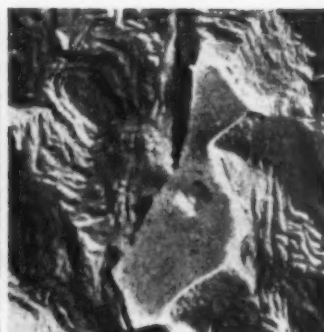
8 (c)



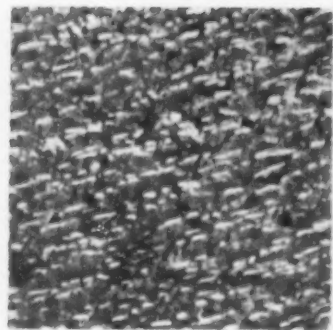
8 (d)



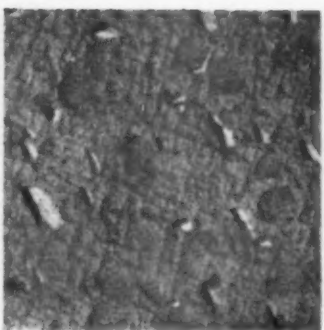
8 (e)



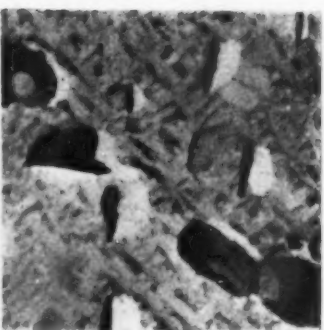
8 (f)



9 (a)



9 (b)

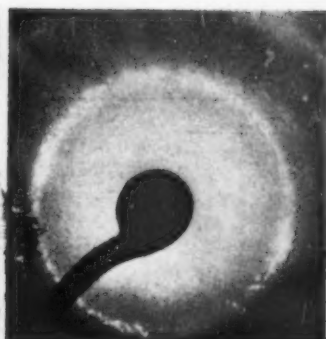


9 (c)

8 Structure of transformer sheet after solution heat treatment. Replicas shadowed with chromium. (a), (b) ferritic matrix, (c) to (f) various states of the grain boundaries $\times 5,000$



9 (d)



9 (e)



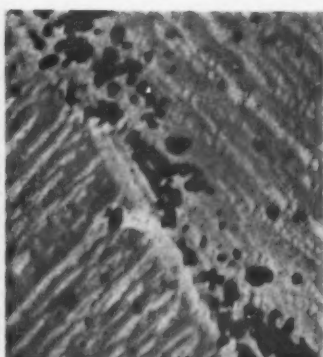
9 (f)



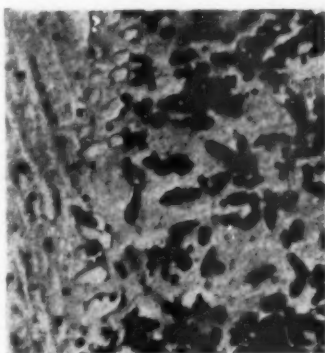
10 (a)



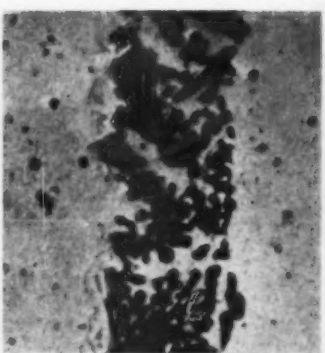
10 (b)



10 (c)



10 (d)



10 (e)



10 (f)

9 Precipitates in the structure of transformer sheet after various precipitation heat treatments. Carbon extraction replicas shadowed with chromium. (a), (b) 250°C., 20 min., (c), (d) 250°C., 30 min., (f) 300°C., 30 min., (e) shows the X-ray diffraction of the precipitate after heating at 250°C. for 30 min. $\times 5,000$

10 Precipitates on the boundaries of the ferrite in transformer sheet after various precipitation heat treatments. Carbon extraction replicas shadowed with chromium. (a), (b) 300°C., 2 h., (c) 450°C., 1 h., (d), (e), (f) 450°C., 4 h. $\times 5,000$
DI

precipitate is deposited on one side of the boundary of the grains also manifests itself in other materials.³⁶

The way in which the precipitate which forms at 450° C. is deposited and its morphologies are shown particularly clearly by the electron microscope photographs in figs. 10 (c) to (f). From these specimens it is evident that they are spheroidal formations which in some areas are interspersed with dendritic formations which can be permeated by the electrons (fig. 10 (f)). In this stage the precipitates were subjected to X-ray structural analysis. In view of the fact that the boundaries and the precipitate formed a small part of the total surface of a polished specimen, the relative quantity of the precipitate was artificially increased in such a way that by several times repeating the grinding of the sheet under examination we progressively took extraction replicas, which were all placed onto a specimen of the matrix (fig. 11). In this way we obtained a specimen for X-ray analysis; apart from the original matrix (a) this specimen also contained an adequate quantity of the precipitated phase (b).

TABLE I X-ray analysis of the precipitates from the transformer sheet after precipitation heat treatment at 450° C. for 4 h.

λ , Å	Intensity	λ , Å	Intensity
Measured		Tabulated for Si_3N_4	
3.80	Moderate	3.86	40
3.35	Moderate	3.40	40
3.08	Very weak	3.10	10
2.90	Moderate	2.87	95
2.60	Moderate	2.58	70
2.52	Strong	2.53	100
—	—	2.48	20
2.43	Weak	2.43	20
2.28	Moderate	2.30	60
2.25	Weak	2.26	20
2.22	Weak	2.23	20
2.16	Weak	2.15	40
2.07	Moderate	2.07	60
2.02	Very strong	(Fe α)	
1.93	Weak	1.93	20
1.88	Weak	1.88	20
1.86	Weak	1.86	20
1.80	Weak	1.80	20
1.75	Weak	1.76	40
—	—	1.75	10
1.59	Moderate	1.59	40
1.51	Weak	1.51	20
1.48	Moderate	1.48	50
1.45	Weak	1.44	40
1.43	Strong	(Fe α)	
1.42	Moderate	1.42	40
1.41	Weak	1.41	30
1.34	Weak	1.35	40
1.33	Weak	1.32	20
1.31	Weak	1.31	20
1.30	Moderate	1.30	30
1.29	Weak	1.295	20
1.26	Weak	1.26	10
1.22	Weak	1.225	20
1.16	Very strong	(Fe α)	

An analysis of the X-ray photograph obtained by means of monochromatic radiation with CrK is given in the table, from which it is to be seen that the overwhelming majority of the X-ray lines of the specimen which was investigated may be attributed to the nitride Si_3N_4 .

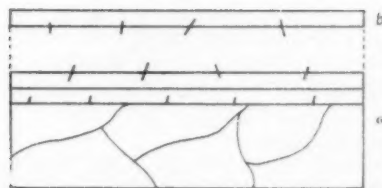
This finding agrees with the hypothesis which follows from our thermochemical analysis; on this basis our judgment is that the spheroidal portion which after heating at temperatures around 450° C. predominates to a decisive extent in the precipitate on the boundaries of the ferritic grains is nitride of silicon, Si_3N_4 . The characteristic dendritic formations probably belong to cementite; its existence during the subsequent stage of the formation of the brittle phase on the grain boundaries has been suggested by certain of the authors of the works mentioned earlier.

During the course of further heating, piling up and coagulation of the particles on the grain boundaries takes place; this is especially clearly shown by the electron micrograph in fig. 12 and their final agglomeration into compact formations (fig. 7 (f)). The precipitation processes are thereby completed, and in the specimen which had been heated for 1 h. at 700° C. there is repetition of the same structure which characterized the original state (fig. 6 (a)).

With the aim of conducting X-ray structural analysis of this final phase on the grain boundaries, we carried out separation of the inclusions from a specimen of the initial sheet by the method of dissolution in a 10% aqueous solution of ammonium persulphate.³⁸ In the isolate obtained it was possible to distinguish visually certain types of inclusions which corresponded in their shape to the formations present in the compact specimen. The fine fraction gave coherent lines on the X-ray diagram which corresponded to the nitride Si_3N_4 . The remaining coarse particles revealed themselves on the X-ray diagram as isolated reflections which did not form coherent lines. Through subsequent rotation of the specimen during the course of exposure further coherent lines were established, the dominant majority of which corresponded to the normal inclusions present in steel; mainly SiO_2 and Al_2O_3 . In no instance were lines typical of Fe_3C revealed on our X-ray diagrams.

Analysis of the results

The structural changes which take place in transformer steel of the composition under investigation after solution heat treatment (1,100° C., 2 h., *in vacuo*) during subsequent heating at temperatures of 50 to 1,000° C., may be divided into various ranges. In the range from 50 to 240° C. precipitation hardening of the basic alpha solution takes place. In this connection it is necessary to mention that Dijkstra²⁰ and Wert³⁹ established in Fe-N alloys



11 Diagram of specimen for X-ray structural analysis: (a) matrix, (b) extraction replicas

the presence of a transitional precipitate, which during heating above 250°C. gradually disappears and is replaced by Fe_4N . Wert maintains that it is a question of platelets running parallel with the planes (100) of the matrix.

The problem of the exact composition of the precipitate from material containing nitrogen and carbon was investigated by Wert⁴⁰ and Köster and Bangert,⁴¹ who supposed that precipitation of nitrogen from the alpha solution is affected by the presence of carbon. Wert considers that the precipitate is a carbonitride, whereas the other two authors are of the opinion that the carbide and nitride form separately, and the presence of sub-microscopic precipitates of cementite only delays the precipitation of the nitride. Booker, Norbury and Sutton, who investigated nitridized layers in steels and in pure iron, found that two types of precipitates are formed.

The first of these is formed of platelets, and their diameter attains a maximum of 3μ in steel and 6μ in pure iron. By electron diffraction it was identified as Fe_{16}N_2 . The second phase is represented by imperfect platelets with diameters of 25μ , which were identified as the nitride Fe_4N . The results of these authors do not show any difference between the lattice parameters of the precipitate originating from pure iron and the precipitate from steel, which would be evidence of the formation of independent nitride and cementite phases. But substitution of the nitrogen by atoms of carbon in the lattice of the phase Fe_{16}N_2 can promote only extremely small changes in the lattice parameters, so that by X-ray structural analysis it is possible to distinguish the purely nitride phase from the carbonitride.

On the basis of our thermochemical analysis and on the basis of a comparison of our morphological and structural findings with the results of the works mentioned, we can draw the conclusion that during heating in the range up to 240°C., from the ferritic matrix of transformer steel of the composition investigated a transition nitride of iron, Fe_{16}N_2 , is precipitated, in which some of the atoms of nitrogen may in some instances be substituted carbon. The space centred tetragonal lattice of this phase has the parameters $a = 5.72 \text{ \AA}$, $c = 6.29 \text{ \AA}$. Morphologi-



12 Coagulation of particles on the boundaries of the ferritic grains, after precipitation heat treatment at 500°C. for 1 h.

cally this carbide manifests itself as platelets of maximum thickness 0.1μ and $1-2\mu$ in diameter.

In the vicinity of a temperature of 240°C. the second stage starts, which is marked by the disappearance of this precipitate in the matrix, and on the thermogram an endothermic arrest is apparent between 240 and 560°C. Gradual breakdown of the transition phase Fe_{16}N_2 ensues, and in the matrix only dispersely precipitated platelets are formed; from their morphology we may judge them to be the phase Fe_4N . At the same time particles start to make their appearance on the boundaries of the ferritic grains. Structural analysis of the particles at the start of this stage is not reliable, but on the X-ray diagrams there are signs of the coexistence of the phases Fe_4N and Si_3N_4 . At 450°C. the matrix is clean, and on the boundaries of the grains are precipitated densely ordered spheroidal particles with diameters of the order of 1μ , which in some areas are alternated with thin formations of a dendritic character. By structural analysis the presence of the phase Si_3N_4 was established.

This second stage is therefore marked by the gradual diffusion of the nitride of iron into the matrix (with eventual continued existence of the nitride Fe_4N as a transition phase), and the precipitation of nitride of silicon on the boundaries of the ferritic grains or eventually on the boundaries of newly formed ferritic sublattices. On the basis of the presence of typical dendritic particles we judge there to be sporadic precipitation of cementite. The small quantity of such cementite was not discernible by X-ray structural analysis. As the end of this stage it is thought that at a temperature in the vicinity of 700°C., the precipitates on the grain boundaries are agglomerated into compact particles and partially into envelopes with dimensions of some tens of microns. In this form the presence of the brittle phase in transformer sheet is

already known. X-ray structural analysis shows that the main component of these formations is made up of the nitride Si_3N_4 .

At high temperatures there exists a third stage characterized by the gradual diffusion of the precipitated phases into the solid solution, which is mainly manifested by an endothermic arrest on the thermogram in the vicinity of 950°C.

Conclusions

By combined investigation of the structural changes in brittle transformer sheet (4.34% Si, 0.02% C, 0.01% N) by means of hardness measurements, thermal analysis, optical and electron microscopy, and X-ray and electronographic structural analysis in the light of the thermochemical analysis, it was shown that the active element which participates in the formation of the brittle phases in the matrix and on the boundaries of the ferritic grains is nitrogen. In the range of temperatures up to 250°C. it is precipitated from the alpha solid solution in the form of the nitrides of iron Fe_{16}N_2 and Fe_4N which are deposited in the matrix.

Nitrogen also participates in a much more harmful form of precipitation of secondary phases at temperatures between 250 and 700°C. During the renewed breakdown of the nitrides of iron in this temperature range, nitrogen is diffused jointly with silicon onto the boundaries of the ferritic grains and forms there a compact phase; in these areas it forms continuous strips of a precipitate of composition Si_3N_4 . On heating to a temperature of 700°C. on the grain boundaries a compact phase exists, the basic component of which is the nitride Si_3N_4 . By heating to higher temperatures it is possible to diffuse this phase into the basic substance, when the excessive brittleness of the sheet disappears.

For the production of transformer sheets these conclusions follow from the results of our work:

(1) Nitrogen present in transformer steel is the cause of the formation of nitride phases which promote intolerable brittleness of sheets produced from this steel. (2) These phases can be dispersed into the ferritic matrix by heating to temperatures over 800°C., and by subsequent rapid cooling (200°C. h.) it is possible to prevent the occurrence of excessive brittleness of the sheets.

From this it is possible to proceed to certain technical-economic conclusions. The dispersion of the nitride phases by the method indicated under (2) above is indeed possible, but in many instances it would demand special processes, not to mention the fact that dispersion of the nitride phase into the matrix cannot improve the magnetic properties. For the production of transformer sheets of good quality, the road for the future will prove to be a steelmaking process which is capable of obviating a high content of nitrogen. Therefore

oxygen converter processes are worthy of concentrated attention, although the possibility is not excluded that within the foreseeable future the use of a vacuum furnace with a calcined electrode will prove to be economically feasible.

Acknowledgments

We wish to thank P. Schier of the Metallurgical Institute of the Czechoslovak Academy of Sciences for the kind favour of enabling us to carry out work on the electron microscope, J. Sevcik for help during this work, H. Tuma for carrying out thermal analyses, and Z. Sruta for painstakingly conducting experimental work connected with X-ray structural analysis.

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Aluminium casting alloys

The first publication to be issued by the Association of Light Alloy Refiners & Smelters Ltd. is entitled 'The properties and characteristics of aluminium casting alloys.' As the title indicates it contains data for all the aluminium casting alloys to British Standard 1490. In addition to specification requirements it gives typical properties and information on the physical, foundry and other characteristics of the alloys as well as a section on heat treatment and a guide to the selection of alloys. It is based on the original ALAR data sheets, but is published in a more compact form and contains considerably more information.

Bend test for hardened tool steels

THE PROBLEM of testing fully hardened tool steels with hardnesses of more than 800 v.p.n. is a difficult one because of the comparatively low ductility which is an inherent property of these materials.

Conventional impact, torsion, torsion-impact and repeated-blow tests have all been tried from time to time, but, although each of these has its uses for certain purposes, none of them has been completely satisfactory.

The Metallurgy Division of the British Iron and Steel Research Association has for some time been carrying out research on the testing of hardened tool steels and has concentrated mainly on developing a bend test for assessing their 'toughness.' This term cannot be defined precisely, but is used to denote the resistance a steel offers to fracture. It is usually regarded as representing a combination of strength and ductility.

It was found to be possible to use conventional tensile tests, but the conditions required are exacting and great care is needed in carrying them out. On the other hand, bend tests provide comprehensive information for the minimum of effort in making test-pieces.

The method developed by BISRA uses a specimen 3 in. long, 0.2 in. wide and 0.1 in. thick. The load is applied at four points and is measured by a strain-gauge. The extension of the specimen is measured in a way that makes it easy to calculate the radius of curvature of the test-piece. The design of the apparatus makes it possible to immerse the specimen in a liquid bath during the test so that it can be heated without affecting the load or extension measurements.

A mechanized version of the apparatus is being designed. A hand-operated version has also been designed which can be attached to a Hounsfield tensometer for carrying out tests at room temperature.

The BISRA test method makes use of an improved method of calculating results. Previously, the 'classical' theory of bending had to be used. This was clearly unsatisfactory, for it was known that this theory applied only to elastic deformation of the specimen, whereas plastic deformation also took place during the test. The results obtained were thus of comparative value only. The new method incorporates a correction for plastic bending and makes it possible to draw a more accurate stress-strain curve. Values of mechanical strengths can now be obtained that are within 2 or 3% of those given by conventional tensile tests.



A laboratory version of the BISRA bend-test apparatus

Interpretation

The properties measured by the bend test have been analysed and as a result some suggestions can be put forward for comparing 'toughness' or 'quality' of different steels by combining measurements of elastic and plastic properties.

The mechanical properties used are the measured limit of proportionality and the breaking strength. It has been found that for any given hardness the limit of proportionality has a best value θ . The ratio L/θ , where L is the measured limit of proportionality, can therefore be taken as a measure of the elastic strength of the specimen (referred to the maximum possible value). The most important factor affecting this ratio is the tempering treatment applied to the steel. A further measure of elastic properties is provided by the ratio L/ϕ , where ϕ is the breaking strength of the specimen. The greater this ratio (for a given value of ϕ) the greater the energy required to fracture the specimen.

Where the specimen has deformed plastically before fracturing, a correction is necessary. This is made by calculating the percentage of fibres that have yielded at fracture. This percentage is denoted by Y . It is supposed that for an ideally tough material $Y = 100\%$ and for a completely brittle material $Y = 0$. Measured values usually lie between 0 and 60% for hardened tool steels, and Y is proportional to the linear plastic deformation.

A balanced appraisal of the 'toughness' or 'quality' of a tool steel can be made by combining the three factors in a single factor Q , where

$$Q = (L/\theta) \cdot (L/\phi) \cdot Y$$

This procedure gives results which appear to be in accordance with the behaviour of steels in service.

PEOPLE

THE FOLLOWING members have been elected to fill vacancies on the Council of the Institute of Metals with effect from the a.g.m. on March 29, 1960:

As president: **Sir Ronald Prain**, O.B.E., HON.M.I.M.M., chairman and president, Rhodesian Selection Trust Ltd.

As vice-presidents: **H. M. Finniston**, B.Sc., Ph.D., A.R.T.C., F.I.M., research manager, C. A. Parsons & Sons Ltd., and **H. W. Hignett**, B.Sc.(ENG.), F.R.I.C., F.I.M., M.I.W., assistant managing director, Henry Wiggin & Co. Ltd.

As ordinary members of Council: **R. W. K. Honeycombe**, M.Sc., Ph.D., professor of physical metallurgy, University of Sheffield; **Ivor Jenkins**, D.Sc., F.I.M., chief metallurgist, research laboratories, the General Electric Co. Ltd.; **E. Robson**, managing director, the Manganese Bronze and Brass Co. Ltd.; **J. Salter**, B.Sc.(TECH.), A.M.I.E.E., director, the British Aluminium Co. Ltd.; **Christopher Smith**, F.I.M., works director, James Booth & Co. Ltd.

Acheson Industries (Europe) Ltd. announces the election of **Mr. Edward A. Smith** to the Board of Directors of Acheson Colloids Ltd., its principal subsidiary.

Mr. Smith was technical manager of Acheson Colloids Ltd. before being promoted to his present senior position of executive manager, Acheson Industries (Europe) Ltd.

Mr. R. E. Huffam has been re-elected for a second term of office as the president of the British Standards Institution. Mr. Huffam was, until his recent retirement, U.K. co-ordinating director of Unilever Ltd. He also holds office as chairman of B.S.I.'s General Council.

Mr. C. H. Flurscheim, B.A., M.I.E.E., MEM.A.I.E.E., a director and the chief electrical engineer of Metropolitan Vickers Electrical Co. Ltd., has been co-opted to serve on the Council of the British Welding Research Association.

Mr. F. C. Braby, M.C., D.L., M.I.MECH.E., chairman and managing director of Fredk. Braby & Co. Ltd., has been elected chairman of the Council of the British Non-Ferrous Metals Research Association to succeed Dr. Maurice Cook, C.B.E., who retires from office at the end of this month.

Mr. Braby, a graduate in engineering of Manchester University, is a prominent figure in the engineering and metal manufacturing industries. A past president of the Engineering and Allied Employers' National Federation and of the London and District Engineering and Allied Employers' Association, Mr. Braby has also contributed much to the managerial efficiency and technical advancement of the galvanizing industry through his service as chairman of the Hot Dip Galvanizers and the Galvanized Tank Manufacturers Associations.

Mr. Braby has played an active part in the affairs of the BNFA since 1929, and has been a member of the Council since 1935. In 1950 he was appointed a vice-chairman and hon. treasurer of the association.

Mr. Bill Swinn—who has been responsible for many instrumentation schemes in the British steel industry—recently made a tour of Spanish steel centres. The tour, to advise on modern trends, had been arranged by Omnium Iberico Industrial S.A.—the Spanish associates of Honeywell Controls Ltd. for whom Mr. Swinn is steel industry sales manager.



Mr. B. Swinn

At the main centres, a paper by Mr. Swinn on the instrumentation of furnaces in the steel industry was read by Mr. Manuel Doblas, representing the local Honeywell distributor. As far as is known, Mr. Swinn's is the only paper on furnace instrumentation printed in Spanish. Mr. Swinn also supervised demonstrations of liquid steel temperature measurement in the plants of individual firms.

Mr. Tibor Haas, DIPL.ING., A.M.I.MECH.E., A.F.R.A.E.S., has been appointed head of the Design Section in the newly-formed Members' Service Department of British Welding Research Association, Abington, Cambs.

Mr. Haas, who was educated at Prague University, Faculty of Mechanical and Aeronautical Engineering, has had many years' experience in mechanical engineering, lightweight engineering design and heavy engineering.

Following a period as industrial consultant on contracts throughout Europe he joined the Bristol Aircraft Company of Filton where, for the past six years, he has held the position of head of the Fatigue Department.

Mr. C. P. Paton has resigned from Northern Aluminium Co. Ltd. to take up an important position with Aluminium Ltd. of Canada in Montreal.

Mr. Taylor Cornelius, who has taken over from Mr. Paton as Northern's general works manager, was elected a director of the company. Mr. Cornelius was until recently a vice-president of Aluminum Company of Canada Ltd. and manager of that company's fabricating division.

OBITUARY

We are sorry to learn of the death of **Mr. R. B. Dakin**, deputy chairman and joint managing director of Walter Somers Ltd.

Mr. Dakin had been 46 years with the firm, starting at 17 years of age and working under the founder, Mr. Walters Somers. He was for a short while manager of the original Haywood Forge. During World War I he was put in charge of the munitions plant where he rendered outstanding service. In 1920 he became secretary of the company, and about 1929-30 became a director.

During the second world war Mr. Dakin took over Munitions Plant, Ministry of Supply, for a year, and afterwards became works manager, then managing director of Walter Somers Ltd. The Doxford crankshaft was produced under Mr. Dakin's direction.

NEWS

Sintered metals conference Distinguished visitors to Swindon

SCIENTISTS and engineers from five of Europe's leading companies in the field of powder metallurgy and sintered metals met at Swindon recently to exchange technical information and to review research and development in their industry.

This exchange of news and discussion of future plans took place during the annual C.O.D.I.R.P. Conference. It culminates the past year's individual research efforts and facilitates group study of outstanding problems.

Each company in turn is host to other member companies and this year the Plessey Co. Ltd. acted as hosts to over 20 delegates from France, Italy, Germany and Sweden.

In addition to Conference sessions and the reading of 17 papers on various aspects of powder metallurgy and sintered metal components, delegates enjoyed a full programme which included visits to Plessey factories at Cheney Manor and Kembrey Street, Swindon.

Companies in the Comité de Direction des Recherches en Metallurgie des Poudres consortium are La Metallurgie Française des Poudres, France, Husqvarna Vapenfabriks, Sweden, Sintermetallwork Krebsoge, Germany, Merisinter, Italy, and the Plessey Co. Ltd.

£2-million expansion scheme for Shepcote Lane

A two-million-pound expansion scheme for Shepcote Lane Rolling Mills Ltd., of Sheffield—owned jointly by Firth-Vickers Stainless Steels Ltd. and Samuel Fox & Co. Ltd.—has been approved by the British Iron and Steel Board and the British Iron and Steel Federation.

Shepcote Lane is already one of the most modern and best-equipped works of its kind in the world. Firth-Vickers, Europe's largest manufacturers of stainless steel, own a two-thirds interest in the mills and Samuel Fox one-third. The enormous increase in the demand for stainless steel during the past nine months, particularly for

consumer products, is the main reason for this new expansion programme.

The new production facilities, which are expected to be in operation in the second half of 1961, will be mainly for stainless-steel wide strip in coil. At present the mills are producing 400 tons a week of stainless-steel coil up to 40 in. wide.

Electric arc furnaces replace open-hearth

Steel, Peech and Tozer, Rotherham, a branch of the United Steel Companies Ltd., is to spend £10 million on the replacement of all its existing open-hearth steel-melting furnaces by six electric arc furnaces of 110 tons capacity each. When completed in about five years' time, this will be the largest electric steelmaking plant in the world with an annual capacity of 1,350,000 ingot tons of steel. It is also the largest single development scheme in the branch's 80-year history.

At the present time, there are 21 open-hearth furnaces at Steel, Peech and Tozer—14 in the Templeborough melting shop and seven in the Rotherham melting shop—producing approximately one million ingot tons of steel per year. The existing Templeborough melting shop is to be adapted to house the new electric furnaces. The Rotherham melting shop will be demolished entirely.

Initially, four electric furnaces of the swing-roof type will be installed, and it is planned to have the first of these in commission by January, 1963. In order to make a start on the plant, however, the first two open-hearth furnaces at the Sheffield end of the Templeborough melting shop will close down in two years' time, to be followed by others as the scheme progresses.

Berkeley's No. 1 reactor pressure vessel successfully stress relieved

With the completion of pressure tests, the No. 1 reactor pressure vessel at Berkeley Nuclear Power Station becomes the world's largest reactor pressure vessel ever to be stress relieved. Working closely throughout with



Mr. R. Hall, commercial executive of the Plessey Company's Swindon Group, points out a feature of the first stage of the proposed expansion project for Machine Products Ltd., the associate Plessey Company which makes sintered metal parts, to delegates attending this year's C.O.D.I.R.P. Conference

In the photograph from left to right are: Mr. K. Loveday, chief metallurgist, the Plessey Company at Swindon, Mr. R. Hall, Mr. G. Brynne, technical director of the Husqvarna Vapenfabriks Company, Sweden, and Mr. I. Ljungberg also of Sweden

John Thompson Ltd., which is responsible for design and construction of the reactor vessel, the stress-relieving installation was planned, erected and its operation supervised by the Electric Resistance Furnace Co. Ltd. Faced with the mammoth task of heat treating in one operation a mild-steel vessel weighing 1,000 tons, this company installed equipment requiring a 2½-MW. power supply.

The reactor vessel, 80 ft. high, 50 ft. in dia. and having a capacity of 142,000 cu. ft., was erected on site from sections of 3-in. and 4-in. thick mild-steel plate. The erection involved 2,500 ft. of welds. In the top and bottom domes of the vessel there are large-diameter ports for the circulation of the gas to be heated by the reactor and other openings in the top dome for the operation and control of the nuclear pile. Inside the vessel the huge steel diagrid for the support of the nuclear unit weighs 165 tons.

The heating of this vessel presented many problems apart from determining the power required and the method of its distribution to obtain uniform heating. Allowances had to be made for change in the shape and size of the vessel because of increased temperature. Accurate temperature measurement and control were essential at a position remote from the vessel. The heaters had to be installed in a humid atmosphere caused by the setting concrete of the outer biological shield.

For the heating of the vessel and its diagrid 8,500 ft. of sheathed radiant heaters were installed. These heaters were mounted on specially designed supports erected within the vessel, which was lagged, externally, with 'Caposite' and 'Rocksill' insulation. The electricity supply to the heaters was carried by a complicated system of busbars entering the vessel through two of the gas ports, which were then closed to reduce heat losses. The heaters were arranged in 24 independently controlled zones, the 24 automatic temperature controllers, together with four six-point temperature recorders, being installed in a separate control room, from where the whole of the stress-relieving operations were regulated.

For the measurement, control and recording of temperatures some 400 thermocouples were used. The control and recording couples were welded to heat-resisting alloy blocks, which were afterwards clamped into contact with the surfaces to be checked. Leads from the control couples were taken direct to the instruments, where

rheostats were used to compensate for increase in the electrical resistance of the couples with temperature rise. Connections to the recorder couples were made through cold junction boxes. The accuracy of the complete thermo-electric circuit was checked during the early stages of the stress-relieving operation.

The minimum temperature specified for the relief of all stresses set up during construction of the vessel was 575°C., and this temperature was reached in 65 h. The heating was continued for another 10½ h., bringing the vessel to within 22°C. of the maximum permissible temperature of 650°C. When the power to the heaters was removed the fall in temperature to 575°C. took 11 h., the whole of the vessel having then been held within the prescribed temperature limits for 21½ h. The natural cooling of the vessel to atmospheric temperature took approximately 11 days.

The complete success of the heating operation was proved by the mass of temperature recordings. These show that the temperature of all parts of the vessel, including the diagrid, rose smoothly at a constant rate and that the temperature distribution was at all times remarkably uniform. In spite of the differences in wall thicknesses of the vessel and in the type of construction involved in the walls and the diagrid, the highest and lowest temperatures recorded at any moment seldom differed by more than 15°C. The ultimate temperature of 628°C. was reached with a uniformity of $\pm 7^\circ\text{C}$. The heat treatment was well within the limits set by appropriate British Standards Specifications for the stress relieving of reactor vessels.

The vessel, which must withstand a working pressure of 125 p.s.i.g., was tested at a pressure of 211 p.s.i.g. and has now been accepted by Lloyd's on behalf of the Central Electricity Generating Board. The Efco heating equipment will be used again to stress relieve the second reactor vessel which is nearing completion.

Efco Ltd. is building another factory in the L.C.C. industrial development area at Sheerwater, near Woking, in Surrey. The site is a prominent corner position close to the factory of its subsidiary, Electro-Chemical Engineering Co. Ltd. The new factory, scheduled for completion early next year, will provide up-to-date facilities for the manufacture of special furnaces.

Brayshaw Furnaces Ltd.

The continuous development of Brayshaw Furnaces Ltd. and Brayshaw Tool Ltd., of West Gorton, Manchester, has been further consolidated by the successful completion of a substantial building improvement programme

Although housed at the same address both firms now have spacious office accommodation designed in a contemporary manner. Developments have also been effected in the works departments and the considerable improvement in space layout and plant is already showing significant results





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*Incoloy - Nickel Alloys v. Corrosion
Monel in Continuous Pickling Plant



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TGA M159

INSTRUMENTATION

OWING to the increasing importance of up-to-date instrumentation in nearly all branches of the metal industries, and also on account of the continued progress being made by the manufacturers of this equipment, we shall describe these recent developments in a separate section in future. Our section NEW PLANT will continue to deal with developments in fields other than that of instrumentation.

Stepless control of power and temperature

An Electr-O-Volt control unit providing continuous, contactorless regulation of electric power is available from Honeywell Controls Ltd. The equipment, which operates with continuous balance measuring instruments, provides an economical and accurate form of temperature control for all types of electrically-heated furnace.

By a proportional adjustment of power input when load changes occur, the unit stabilizes furnace temperature continuously, without the wear and maintenance involved in constantly operating switch gear. Because the control action is non-cyclic, temperature changes in the heating elements occur gradually, and over a smaller range than when on/off systems are used. The furnace structure and elements are thus operating under less arduous conditions, giving longer life to certain equipment—which needs more frequent replacement under pulsing control. Closer control is possible than with rapid on/off pulsing systems.

The Electr-O-Volt provides non-interacting, three-mode control—proportional, integral and derivative action. The output from the controller is a direct current varying between 0.3 and 5 mA., which can be fed into any load between 2,000 and 8,000 Ω . For induction or resistance heating temperature control, the output is fed to a magnetic amplifier, the output of which is connected to the control windings of a saturable reactor. The reactor thus continuously varies power input to a furnace in order to maintain the pre-set control temperature.

The unit finds applications in crystal growing, and all types of electrically-heated furnace (fig. 1). It can be used with positioners in fuel-fired installation or processing industries to give instantaneous stepless operation of control valves located at long distances from the control panel. Further applications include heat treating, annealing and diffusion furnaces, die casting, creep testing, etc.

Pulse, number 1

A new publication by Kelvin & Hughes (Industrial) Ltd. is designed to give regular information on this company's non-destructive testing equipment and electronic instrumentation. The first number, which appeared recently, has some short articles of considerable interest on the application of ultrasonic techniques. It also contains a detailed contribution by A. C. Rankin, F.I.M., on the subject of ultrasonic butt-weld testing. We look forward to future copies of this well-produced house journal with some interest.

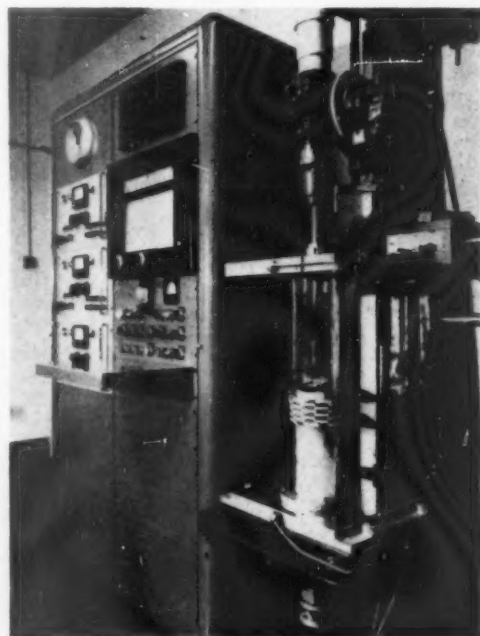
Dewpoint meter

A dewpoint meter developed in America and now being manufactured in this country under licence is finding, by virtue of its easy operation and consistent accuracy, appli-

cations in a wide range of processes where moisture contents of dry air and other gases must be determined. Typical uses of the meter include checking the dryness of air supplies for refrigeration and air conditioning and of atmospheres used in heat-treatment processes. Other uses have been found in the operation of supersonic wind tunnels, the assembly of high-voltage transformers and the making of glass-to-metal seals.

The meter, known as the Alnor Dewpointer, is portable and self contained, requires no coolant, and has a measuring range from -80°F . to room temperature or from 0.0015% to about 2.75% water vapour by volume. The measurements are made by compressing a sample of the gas to a pressure at which, on suddenly releasing the pressure a mist is formed, the temperature of the dewpoint then being calculated from the temperature and pressure ratio before expansion. Easy conversion of the sample temperature and pressure ratio to dewpoint temperature is made with an Alnor Dewpoint calculator.

The gas to be checked is drawn through the meter into an observation chamber with a hand pump, the chamber being fitted with a purging valve to allow a previous gas sample to be cleared. The chamber is illuminated to make



1 Germanium crystal growing temperatures—measured by sapphire rod radiation pyrometer—are maintained within 0.1°C . by this Electr-O-Volt system at the crystal growing works of J. Stone Ltd., Crawley, Sussex

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ensure reliability
in bolted constructions



TYPICAL MECHANICAL PROPERTIES OF:

EN III

nickel-chromium steel are as follows:

For high tensile steel bolts needed in locations where stress is a factor, designers specify nickel alloy steels, and quite usually the nickel-chromium alloy steel En III, the properties of which are quoted below.

En III nickel-chromium steel is specified for connecting rod bolts by leading manufacturers of passenger cars, buses and tractors. The design of these bolts is highly individual as will be seen from the illustration which shows three examples from the current production of Acton Bolt Co. Ltd., Acton, W.4, who supply leading British and American companies in the automotive trade.

In this competitive business, the basic aim is to provide the high tensile properties required at the lowest cost. This aim is achieved by cold heading, thread rolling and the use of nickel-chromium steel.

SIZE	HEAT TREATMENT	Yield Point t.s.i.	Maximum Stress t.s.i.	Elongation per cent	12d ft. lb.
3½" sq.	Oil quenched 830° C	36.8	50.9	26	75
2½" dia.	Tempered 600° C	47.4	55.6	22	75
1½" dia.		50.8	59.2	21.5	59

By utilising the better properties obtainable in more highly-alloyed nickel steels, dimensions can be reduced, lighter constructions produced, distortion through heat treatment minimised and reliability and economy achieved.

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TGA 11/514



2 The Alnor Dewpointer

the mist easily visible. The pump is designed to prevent the slightest trace of moisture being introduced into the chamber by the wiping action along its barrel. The meter is fitted with a sensitive thermometer mounted in clear perspex and a pressure-ratio gauge to give quick, direct readings of the ratio of atmospheric pressure and observation-chamber pressure. The meter can be battery operated or connected to the mains.

The Alnor Dewpointer is being marketed in this country by the Electric Resistance Furnace Co. Ltd., a subsidiary of Efco Ltd.

Polarographic analysis

The KOVO P.576 Polaroscope is an oscilloscope specially adapted to polarographic analysis. The method is based on the principle of an electrode system through which is allowed to pass an a.c. of 50 c./s. from a 300-V. power supply of high internal resistance; the polarizable electrode is charged during one cycle of the a.c. within a potential range from 0 to -2 V., and then back again from -2 V. to 0 (depending on solution composition). The electrode process is shown on the CR-tube, where the course of the potential derivation with regard to time (vertical direction) is shown depending on the electrode potential (horizontal direction).

Adjustment of the instrument is very simple. The results can be observed immediately after adjusting a suitable intensity of the a.c. current, the d.c. component and setting the required size, brightness and sharpness of the picture. The oscillogram shown on the CR-tube is oval in shape for a pure basic electrolyte, the upper half representing the cathodic, and the lower half the anodic process. Following the introduction of a depolarizer into the electrolyte, the curve shows incisions in both anodic and cathodic parts. The depth of the incision is proportional to concentration, and its position is characteristic of the depolarizer. The mutual position of the cathodic and anodic incisions is a measure of the reversibility of the

electrode process. If they are situated at the same potential, the process is reversible; if displaced horizontally, or if one of them is absent, the process is irreversible.

The instrument is suitable for analysis in the range 10^{-3} to 5×10^{-9} M. Concentrations down to 10^{-9} M can be reached by electrolytic concentration (turning the 'micro' switch on the instrument) or by a hanging-drop method. Comparative titrations can be performed by using twin electrode systems and observing two oscillograms displaced horizontally. Titrant is added until the depth of incisions coincide. Isomers and compounds of similar structure can be very easily examined and identified.

Overall size is approximately $10 \times 14 \times 14$ in., and a mechanical drop time controller is accessory to the instrument.

The KOVO LP.54 Manual Polarograph is an elegantly-styled, conventional d.c. polarograph with one unusual feature which makes it semi-automatic. A recorder is built into the instrument, and light reflected from the galvanometer shines on the nearly transparent paper from behind. The knob which increases the voltage across the electrolyte cell also advances the recorder paper; one can thus plot the polarogram directly on to the paper. Sensitivity is similar to other d.c. polarographs.

The KOVO LP.55A Polarograph is a photographic recording instrument of a type not manufactured in the U.K. A sensitivity of $0.1 \mu\text{A}$. full-scale deflection is obtained by suspending its galvanometer on a cantilever 3 ft. above the instrument. Operation is motorized and fully automatic, once the voltage range that it is required to scan has been set on the instrument. Automatic recording of abscissae after every 100 or 200 mV. is performed, so that the photographic record can be easily evaluated.

These three polarographic instruments are exported by KOVO, the Czechoslovakian State Import/Export organization for the scientific instrument industry, and are sold and serviced in the U.K. by the sole agents, Nash & Thompson Ltd., Hook Rise, Tolworth, Surbiton, Surrey.

These instruments have been designed at Professor Heyrovsky's Polarographic Research Institute in Prague and are already widely used in Eastern Europe and Baltic countries.



3 The Kovo
Polaroscope

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SITUATIONS VACANT

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There are vacancies in the Heat Treatment Department at Great King Street for Metallurgists of graduate or A.I.M. level. The work is concerned with diffusion techniques involving the use of solid, liquid and gaseous media and electrical methods. The post is permanent and pensionable. Salary according to experience but not less than £970 per annum. Apply in writing, giving full details of age, qualifications and experience to the PERSONNEL MANAGER, JOSEPH LUCAS LIMITED, Great King Street, Birmingham, 19, quoting reference PM GR 334.

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METALLURGIST (Scientific Officer) required by Ministry of Aviation at National Gas Turbine Establishment, Pyestock, Farnborough, Hants., for basic studies of behaviour of wide range of materials for high-temperature service; primarily on effects on fracture of thermal stresses, structural factors and environmental conditions. 1st or 2nd class honours degree in metallurgy, or equivalent qualification, required. Salary range £615-£1,090. F.S.S.U. terms. Opportunities for establishment if under 31.—Forms from Ministry of Labour, Technical and Scientific Register (K), 26 King Street, London, S.W.1, quoting reference F.803 9A.

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UDDEHOLM LTD., well known as the British associate company of Uddeholms Aktiebolag, the large and old-established Swedish steelmaking, forestry and chemical concern, have a vacancy in their Midland area sales organisation. Candidates should have a sound knowledge of tool steels, their heat treatment and applications particularly in the hot-work field. Preference will be given to those with sales experience. The company operate a non-contributory pension scheme and only men with drive and initiative, now earning a four-figure income, should apply, giving full details of age, education and experience, in writing to: Manager, Tool Steel Division, Uddeholm Ltd., Crown Works, Birmingham 3.

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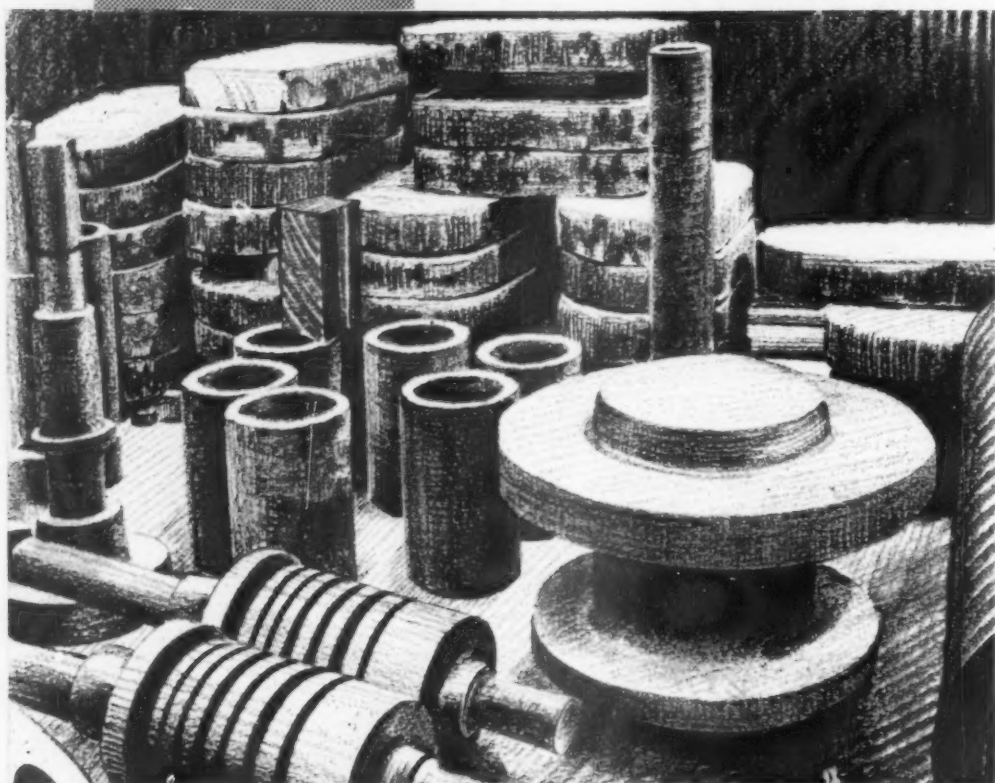
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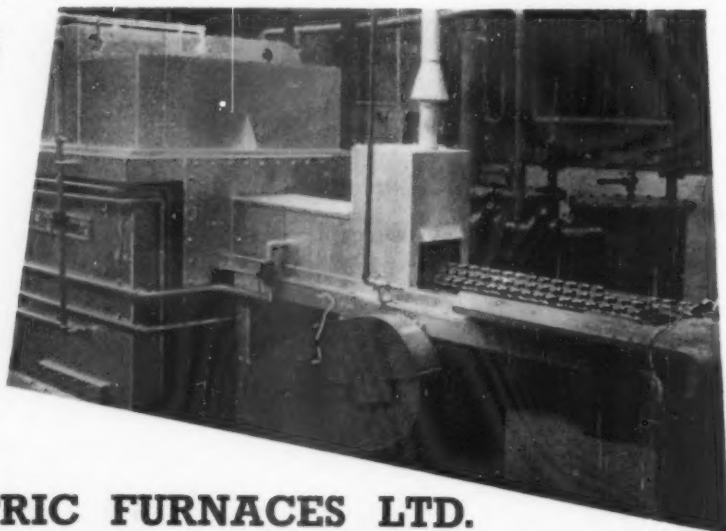
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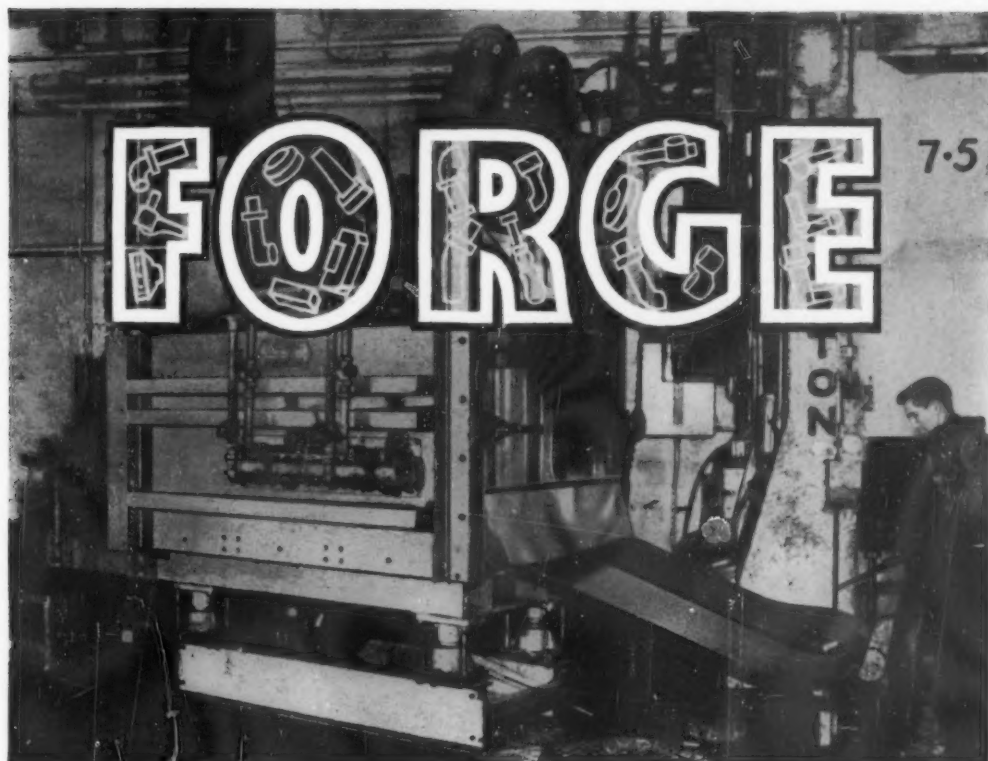


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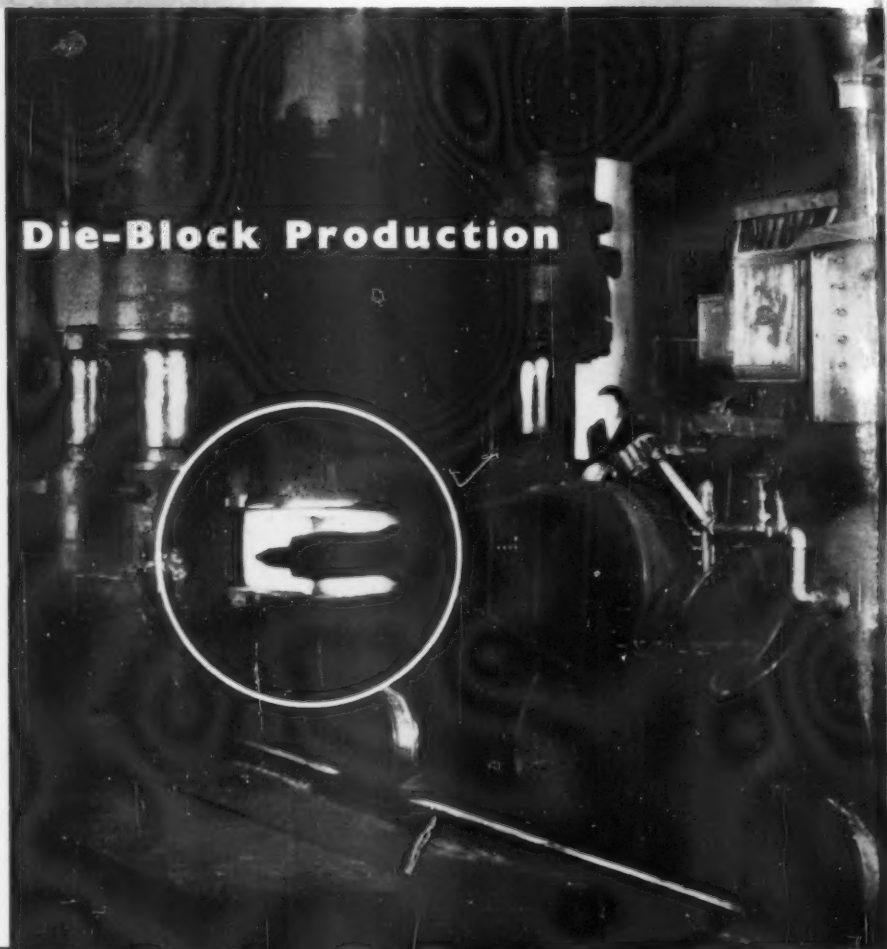
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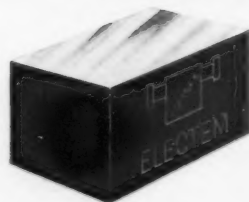
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